NCR-days 2007

a sustainable river system ?!

November 15 – 16

A.G. van Os (editor)

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Abstract

NCR is the abbreviation for the Netherlands Centre for River studies. It is a collaboration of ten major scientific research institutes in the Netherlands, which was established on October 8, 1998.

NCR's goal is to enhance the cooperation between the most important scientific institutes in the field of river related research in the Netherlands by:

- Building a joint in-depth knowledge base on rivers in the Netherlands in order to adequately anticipate on societal needs, both on national as well as international level;
- Strengthening the national and international position of Dutch scientific research and education;
- Establishment of a common research programme.

NCR strives to achieve this goal by:

- Committed cooperation, in which the actual commitment of the participating parties is expressed;
- Offering a platform, which is expressed by the organisation of meetings where knowledge and experiences are exchanged and where parties outside NCR are warmly welcomed.

The committed cooperation and collaboration is based on a programme. This programme was first published in October 2000 and was actualised in August 2001, August 2004 and November 2006.

The platform function is expressed amongst others by the organisation of the so-called annual NCR-days. The publication at hand contains the proceedings of the NCR-days, organised on November 15-16, 2007.

The proceedings of the NCR-days 2007 are sub-titled 'a sustainable river system ?!'.
This is subdivided in the themes (i) Fluvial Processes, (ii) Flood Risks and (iii) Water Management.

Samenvatting

NCR staat voor Nederlands Centrum voor Rivierkunde. Het is een samenwerkingsverband van tien wetenschappelijke onderzoekinstituten in Nederland dat op 8 oktober 1998 is opgericht.

Het doel van NCR is het bevorderen van samenwerking tussen de belangrijkste wetenschappelijke instituten op het gebied van rivieronderzoek in Nederland door:

- het opbouwen van een kennisbasis van voldoende breedte en diepte in Nederland omtrent rivieren waardoor adequaat kan worden tegemoet gekomen aan de maatschappelijke behoefte, zowel nationaal als internationaal;
- het versterken van het wetenschappelijke onderwijs en onderzoek aan de Nederlandse universiteiten;
- het vaststellen van een gezamenlijk onderzoekprogramma.

NCR wil dit doel op twee manieren bereiken:

- via *gecommitteerde samenwerking*; hierin komt het daadwerkelijke commitment van deelnemende partners tot uiting;
- via het bieden van een *platform*; deze functie uit zich in het organiseren van bijeenkomsten, waarop kennis en ervaringen worden uitgewisseld; andere partijen zijn daarbij van harte welkom.

De gecommitteerde samenwerking geschiedt op basis van een programma. Dit programma is in oktober 2000 voor het eerst in het Nederlands gepubliceerd en geactualiseerd in augustus 2001, augustus 2004 en november 2006.

De platformfunctie komt onder andere tot uiting in het jaarlijks organiseren van de zogenaamde NCR-dagen. De voorliggende publicatie bevat de “proceedings” van de NCR-dagen die gehouden werden op 15 en 16 november 2007.

De proceedings van de NCR-dagen 2007 dragen de subtitel ‘a sustainable River system ?!’, vrij vertaald ‘een duurzaam riviersysteem ?!’.
De verschillende subthema’s van de NCR-dagen 2007, (i) rivierprocessen (ii) overstromingsrisico’s en (iii) waterbeheer, dekken een groot gedeelte van het hedendaagse onderzoek dat in Nederland op rivierkundig gebied wordt uitgevoerd.

the ladies of Bureau Routine

Preface

These proceedings are the product of the NCR-days 2007, held on 15-16 November 2007. The NCR-days are a yearly conference at which mainly young scientists present their ongoing research on a wide variety of fluvial subjects. Since 2000, the NCR-days have been organised in rotation by different institutes represented in the Netherlands Centre for River Studies (NCR).

The NCR-days of 2007 were special because they were connected to the 300-year celebration of the opening of the Pannerdensch Kanaal on 14 November. They were organised by the NCR secretariat with the help of Bureau Routine and an organising committee from the NCR Programming Committee, Frans van der Knaap, Henk Wolfert and Rob Lenders.

The NCR-days were held on the ship River Dream (15 November), sailing over the River Rhine and the Pannerdensch Kanaal and in the Conference Centre 'Westerbouwing' (16 November). The latter is an excellent location for a conference on rivers: it sits on top of a steep hill offering a magnificent view on the river Neder-Rijn and its floodplain. In these inspiring settings, we welcomed some 100 participants.

The first day two key notes were presented and two workshops on sustainable river systems were held. On the second day 13 participants gave an oral presentation and 17 posters were presented and discussed.

The contributions (oral presentations and posters) to the conference resulted in the 27 papers in this proceedings volume. The papers have been arranged into sections that basically represent the various sessions of the conference.

The organisation of the workshops was in the able hands of Max Schropp and Chris Seijger from RWS. We thank them for their excellent job.
We also wish to thank the chairmen of the sessions Frans van der Knaap (Deltares), Henk Wolfert (Alterra) and Joop de Schutter (Unesco-IHE), the participants introducing the workshops Jaap Kwadijk (Deltares), Wim Silva (RWS), Piet Rietveld (VU) and Hendrik Havinga (RWS), and our keynote speakers Gerard van de Ven and Gerben Ekelmans (SBB).
Special thanks is due to the two chairwomen of the workshops Marja Menke of Arcadis and Marita Cals of Cals Consultancy. They succeeded in fostering a very lively discussion in 10 discussion groups and an interesting feedback from these groups.

Finally we wish to thank Tine Verheij of Bureau Routine and Jolien Mans of NCR. They saw to all the logistics of the two days and provided the photo's for these proceedings.

The funding by Rijkswaterstaat and the Netherlands Organisation for Scientific Research (NWO) is gratefully acknowledged.

The NCR-days have proven to be an attractive platform for exchange of ideas and discussion serving the community of developers and users of expertise on rivers. The 2007 edition was an example of this.

Ad van Os

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The Rhine River: view from the Westerbouwing

NCR-days 2007; Introduction

A.G. van Os
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The Netherlands Centre for River studies (NCR) is a collaboration of the major developers and users of expertise in the Netherlands in the area of rivers, viz. the universities of Delft, Utrecht, Nijmegen, Twente and Wageningen, Unesco-IHE, Alterra, RWS, TNO and WL | Delft Hydraulics. The latter three have formed the research institute Deltares as of January 1st 2008.
NCR's goal is to build a joint knowledge base on rivers in the Netherlands and to promote co-operation between the most important scientific institutes in the field of river studies in the Netherlands.

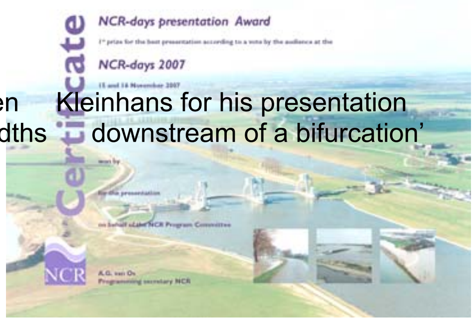
NCR has two key functions:
- *Network or platform function*: this function is reflected in the organisation of meetings at which expertise and experience are exchanged; other parties are very welcome to attend.
- *Research-orientated and educational co-operation*: in which a real commitment of the partners is reflected.

To perform its first key function NCR aims to provide an open platform for all people interested in scientific research and communication on river issues.
To that end NCR organises once a year the so-called NCR-days, where on two ongoing consecutive days scientists present their river studies, in order to maximise the exchange of ideas and experiences between the participants and to provide the researchers a sounding board for their study approach and preliminary results. Based on these contacts they can improve their approach and possibly establish additional co-operation.

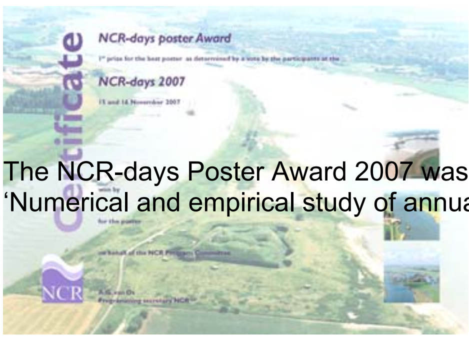
NCR organised these NCR-days for the eighth time on November 15th and 16th, 2007. They were held on the ship River Dream (15 November), sailing over the River Rhine and the Pannerdensch Kanaal and in the Conference Centre 'Westerbouwing' (16 November).

The NCR Programme Committee decided in 2003 to establish the NCR-days Presentation and Poster Awards. They both consist of a Certificate and the refunding of the participation costs for the NCR-days. Therefore, 2007 saw the first lustrum of the NCR-days Awards.
The participants determined the winners. To that end, each participant received four evaluation forms (two for a specific presentation and two for a specific poster) at the registration desk. They were selected at random.
The participants took their 'evaluation job' very seriously. This added considerably to the liveliness of the discussions during the intermissions and poster sessions.

The poster sessions are a very important part of the NCR-days. We use the 'Hyde Park Corner approach' where the primary poster authors are given the opportunity in 'two-minute-talks' to give the participants an appetite to come and see the posters and discuss the content with the authors. This worked again very well.
I had the pleasant task to announce the winners of the NCR-days Awards at the end of the NCR-days.



The NCR-days Presentation Award 2007 was won by Maarten Kleinhans for his presentation 'Long-term evolution of meanderingchannels with adjusting widths downstream of a bifurcation' (see page 18).



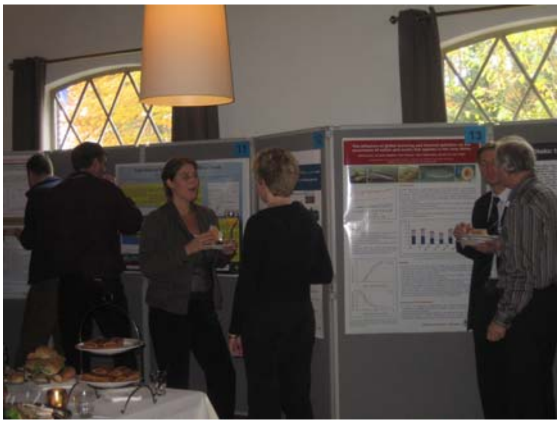
The NCR-days Poster Award 2007 was won by Lisette de Bruijn and Mijntje Crone for their poster 'Numerical and empirical study of annual flood dynamics in the Volga-Akhtuba floodplain' (see page 48).

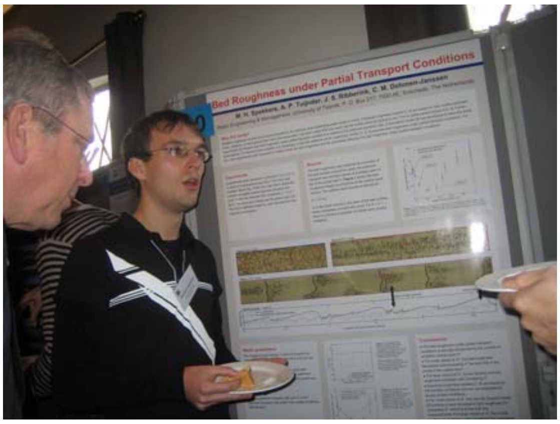
Impression of the Poster Session

Poster introduction 'Hyde Park Corner style'

the winners of the NCR Poster Award 2007, Lisette de Bruijn and Mijntje Crone

overview of posters





discussion in front of the posters

senior researcher of NCR partners discussing posters with poster author and among themselves

Key Notes

Summary by A.G. van Os
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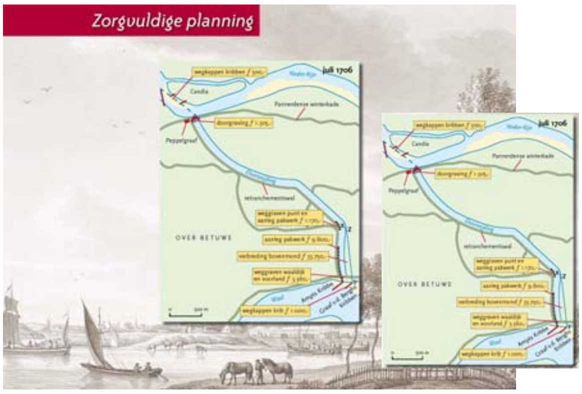
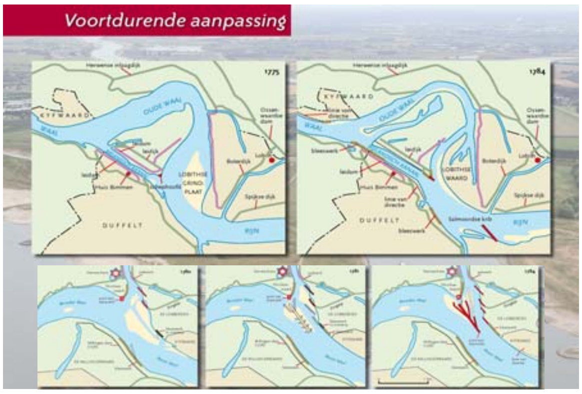
Introduction
At the first day, two inspiring Key Notes were delivered by professor Gerard van de Ven and Mr. Gerben Ekelmans.

The history of the Pannerdensch kanaal by professor Gerard van de Ven

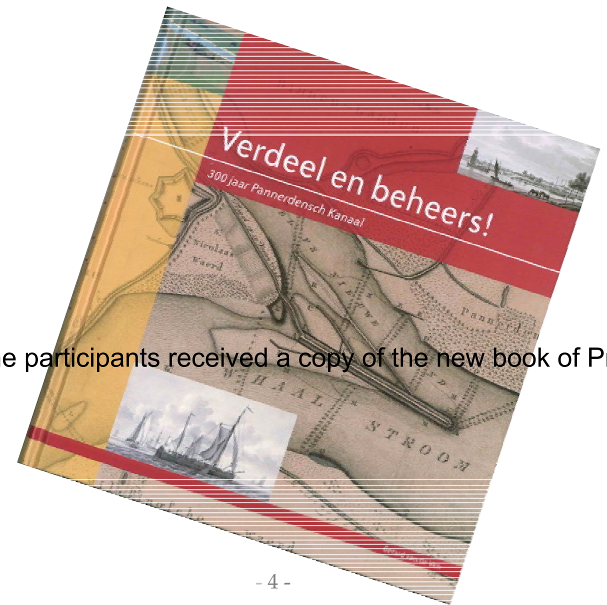
Professor Van de Ven lectured on the history of the Pannerdensch Kanaal, which is a special stretch of the River Rhine.



Key words in his talk were meticulous planning



and a continuous adjustment to changing circumstances.



At the end of the first day, the participants received a copy of the new book of Prof. Van de Ven, ‘Verdeel en Beheers’.

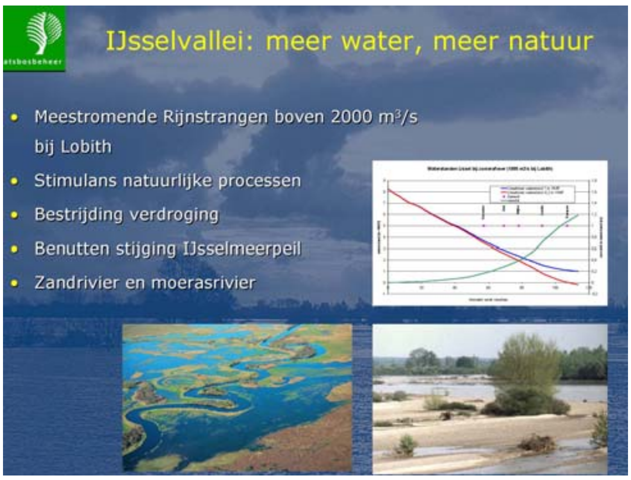
River Nature and Distribution of Water by Gerben Ekelmans

Mr. Ekelmans gave an inspired overview of the ideas of Staatsbosbeheer (SBB, the Governmental Forest Management Department of the Netherlands) regarding the ecologically friendly management of the Dutch River corridors, stressing the need of an integrated approach

- aiming at a natural safety as starting point
- considering Nature as a robust foundation for any management policy to be adopted
- and aiming at characteristic sceneries and an inviting biotope.

He introduced the various management areas of SBB, such as the ‘Duursche Waarden’, the ‘Millingerwaard’ and the ‘Klompenwaard’.

His talk culminated in a call to consider the IJssel valley as the ideal climate buffer of the Rhine Delta, both from a flood management perspective as well as from an ecological perspective.



Visit to the Klompenwaard

After the Key Note of Mr. Ekelmans a visit to the ‘Klompenwaard’, including the ‘Pannerdensche Kop’ (the isthmus dividing the River Rhine into the River Waal and the Pannerdensch Kanaal (= continuation of the River Rhine)) was paid.
This visit was accompanied by Messrs. Gerrit van Scherrenburg, Arnoud van Utrecht en Roel van Ark from SBB, who gave a very vivd and expert guided tour in the area around ‘fort Pannerden’, the former military defence fortress situated at the Pannerdensche Kop.


NCR

Workshops

Summary by Chr. Seijger[1] and A.G. van Os[2]
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Sustainable river management during high water levels

Introduction
The Room for the River project is preparing the Rhine branches (and surrounding areas) in the Netherlands for higher water levels and discharges. This project has to be completed in 2015, so it is a matter of interest to see how sustainable the measures are that have already been taken or will be taken in the near future.
The measures that are being taken right now are designed for a peak discharge in the Rhine branches of 16000 m^3/s; this is a discharge that probably will occur once in every 1250 years. The whole project consists of various measures to give more space to the various river branches. Deepening of fore lands, relocation of dikes, creating extra flood channels, the removal of obstacles in the flow channel and other measures will be taken. The ultimate question is whether all these measures really protect us in the coming future. Alternatively, should we carry out additional projects?

Set-up of Workshop
Marja Menke of Arcadis chaired the workshop.

She is working closely with the project-organisation of Room for the River and has a thorough knowledge of all the processes involved.

During the introduction of the workshop two short presentations were given, showing two different lines of thought.
Firstly Jaap Kwadijk from Deltares | Delft Hydraulics reflected on the topic from a scientific point of view. He gave an answer to the question what sustainability actually is. He showed the sustainability of Room for the River from three different perspectives, together forming a combination of real sustainability. These perspectives were the social/cultural, economic and nature/environment perspective.
After Jaap Kwadijk, Wim Silva from Rijkswaterstaat Waterdienst (Governmental Publics Works Department, Centre for Water Management) gave his view on the high water topic from a practical point of view, the side of the river manager. Main point of his message was that the Room for the River project is really sustainable because it prepares us for a peak discharge that only will occur once in 1250 years.

Discussion
After the participants had heard the scientific and practical side of the story it was time to split up in discussion groups. These groups were a mixture of all participants, coming from different backgrounds, so the discussion was between people of research institutes, universities, consultants and river managers. The objective was to get a vivid discussion within the groups, reflecting on the problem from different angles.

The instruction to the discussion groups was threefold:

1. Sketch — in accordance with your ideas — in the map of the Rhine basin what a sustainable river basin looks like
2. Discuss how to deal with new developments, and the necessity to introduce certain rules for these developments?
3. What advice would you give to the ministers of the European Union and the Dutch minister in particular?

In the plenary session after the discussion in groups, it became clear that all groups had serious discussions, but that it was difficult to come up with additional measures that really improve the sustainability of the river basin during high waters.
Advices varied from building floating houses to water storage basins in Germany, and from increasing the capacity of the IJssel to extra storage in the Lake IJssel.

Rijnstroomgebied

Sustainable river management during low water levels

Introduction

It is often said that low water levels are a more serious problem to river management than floods, because low water levels occur more often, last longer and are more difficult to take measures against. However, the public awareness of low water situations is less than of floods, because the direct danger for people is much smaller.

Set up of Workshop

Chair of this workshop was Marita Cals from Cals Consultancy.
Also in this workshop two presentations were given, one that looked to the low water problem from a scientific point of view and one that viewed the problem from the practical/managerial side.
Professor Piet Rietveld from the Free University Amsterdam (VU) reported research his group performed on the economic effects of low water levels on the inland waterway transport. He showed that an average summer with low water levels generates an economic loss in the waterway transport of some €29 million. But an extreme dry year such as the one of 2003 generated a loss of as much as €92 million. Because more dry summers are likely to occur, this loss can become an important issue.

Subsequently Hendrik Havinga, senior advisor at Rijkswaterstaat, Directorate East Netherlands and associate professor at Delft University of Technology showed the problem of the autonomously lowering riverbed degradation. He also talked about the study-project (Sustainable Fairway Rhinedelta) that Rijkswaterstaat is running to obtain a sustainable navigation channel in the Rhine. Measures investigated in this project are sediment supply, the construction of longitudinal dams along the embankments that maintain the navigation channel during low water and dredging.

Discussion

After these presentations it was again time for the participants to split up in the same discussion groups as in the first workshop.

The discussion groups had two instructions:

1. Germany keeps the Rhine bed fixed, so there is no possibility for erosion of the riverbed anymore. Should we also fix our riverbed to counteract the riverbed lowering?
2. What advice would you give to the ministers of the European Union and the Dutch minister in particular for solutions to the low water problem?

The outcome of the discussion groups was quite diverse. Many groups wanted to fix the riverbed, but there were also groups that argued that from an ecological point of view fixing the riverbed was not an option.
Other groups came up with smart (under water) weirs that would not impede the ships navigating on the river.
Adapting the existing groynes in the river was also seen as a solution for the low water problem.
An important final remark was that there are much more problems with low water levels then discussed in this workshop, e.g. salt intrusion, lack of cooling water for power plants and low oxygen concentrations.

Conclusion of both Workshops

After two Workshops, it became clear that everybody found it really interesting to participate in the discussion groups and to hear different ideas from different backgrounds. Of course there was not always consensus on the different propositions, but that kept the discussions challenging and vivid. And this gave also room to discussions between groups in the plenary session.
The objective of both workshops was to put scientists and practitioners together at one table, discussing the same problems. The outcome of the two workshops was of less importance, since they are part of an ongoing process of thought about appropriate measures for these complicated problems of flood and drought.
This certainly worked out well. The discussions showed that we succeeded in our aim admirably thanks to the participants and the chairwomen.

Trench evolution in the Paraná River

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Abstract
Computational models play an important role in modern engineering applications. In river morphology such models can be used to help in determining the effect of man-made structures on the morphological evolution of the river and vice-versa.

One numerical method which is gaining popularity in many engineering applications is the Discontinious Galerkin finite element method (DGFEM). It is a method which depends on the information at one grid cell and its neighbours only. It allows higher order solutions as well as grid refinement in areas of interest. These properties can lead to the speeding up of simulation time. The presented model uses the above approach to solve the one-dimensional depth-averaged shallow water equations (SWE), a sediment balance and an empirical sediment transport equation.

A man-made trench in the Paraná River, will serve as a validation of the code. The trench was created used to measure transport rates in the vicinity of a tunnel, which almost collapsed after a large dune partially uncovered it. Using the above model it was possible to reasonably reproduce the bed-level measurements in this region.

Introduction

Background
A subfluvial tunnel runs beneath the middle reach of the Paraná River linking the cities Santa Fe and Paraná in Argentina. Due to the buoyancy of the tunnel structure (see Fig. 1) there needs to be a minimum of 4 metres of sand above the tunnel to keep it in place (Serra and Vionnet, 2005). After the flood in 1983 a large dune uncovered part of the tunnel leading to a potentially disastrous situation. The tunnel structure had to be immediately stabilized. To estimate bed-load transport rates in this region a trench was dug in a measurement campaign in 1992.

Objective
The objective of the study was to develop a numerical model for sediment transport capable of predicting changes in the bed level using the DGFEM. The trench in the Paraná River would serve as a validation case.

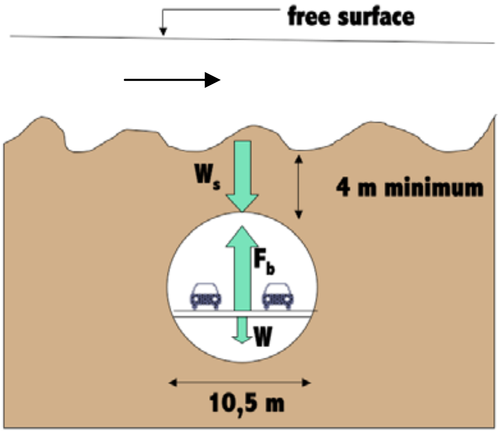

Figure 1. Schematisation of the tunnel linking Santa Fe and Paraná indicating the minimum of 4 metres of bed-material needed to counteract the buoyancy of the tunnel.

Method
A one dimensional depth averaged setting is used to model the transport of sediment and water. The water column is modeled using the SWE which model the conservation of mass and momentum (Stoker, 1957). The sediment is assumed to have a uniform grain size and to be evenly packed. The transport capacity s_b of the bed material is modelled through an empirical equation depending on the local flow velocity u and bed-slope dh_b/dx (see e.g. Schielen et al., 1993).

$$s_b = \alpha \left(\frac{u}{|u|} - \kappa \frac{\partial h_b}{\partial x} \right) |u|^{\beta_b} \tag{1}$$

In Eqn. (1) parameter α is an empirical multiplication factor, β_b describes the non-linearity of the transport formula and κ is a parameter which accounts for the difficulty of sediment moving uphill. The net change in the bed level h_b over time t is given by the gradient of the transport capacity s_b in x (Eqn. 2).

$$\frac{\partial h_b}{\partial t} + \frac{\partial s_b}{\partial x} = 0 \tag{2}$$

To translate the above model into a computational model the domain is partitioned into grid cells. The information about the water depth, momentum and bed-level is approximated by linear polynomials in each grid cell. Across the boundary of two neighbouring grid cells the solutions may be discontinuous (hence the name DGFEM). To advance the solution one step in time, the SWE are solved using an analytical steady state solution (Houghton and Kasahara, 1968). After this a Riemann solver calculates how much sediment should be passed from one grid cell to the next. Using the new bed-level the solution to the SWE can be calculated once again and after that the bed level can be updated as before. This loop is repeated until the prescribed time has been reached.

Results

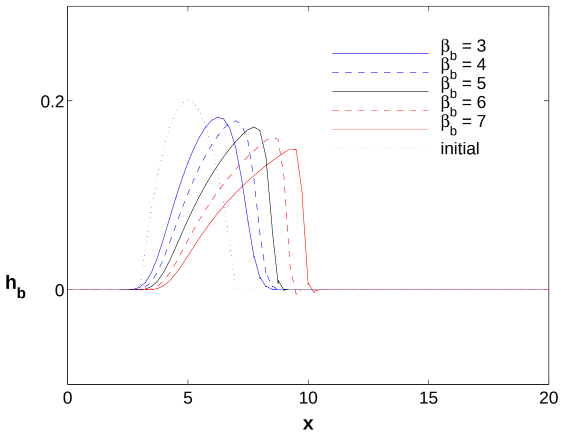

Figure 2. Evolution of an isolated ridge in the river bed for varying values of β_b and constant α and κ.

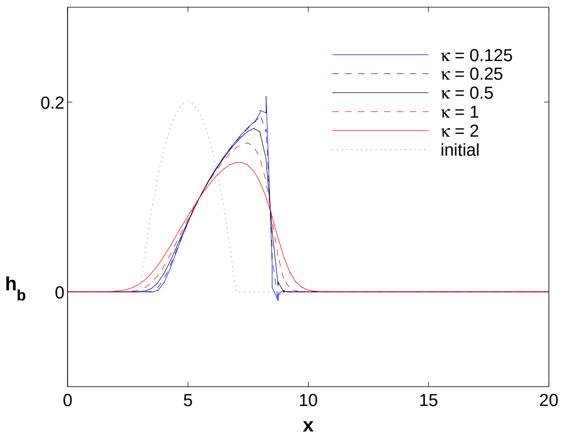

Figure 3. Evolution of an isolated ridge in the river bed for varying values of κ and constant α and β_b.

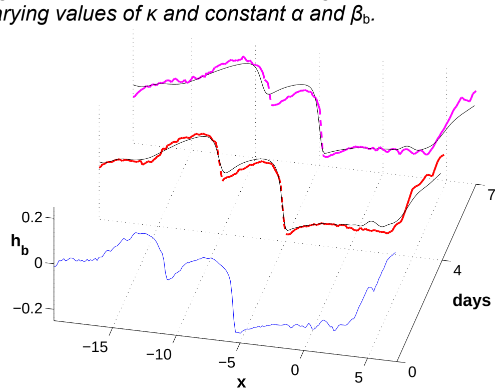

Figure 4. Comparison of the model results and the measurements after 4 and 7 days.

Initial testing of the numerical model was done by simulating the flow over an isolated ridge. The water flows in positive *x*-direction. These initial simulations are to test stability as well as the sensitivity to the parameters β_b (see Fig. 2), and κ (see Fig. 3). Note that the results of the bottom level and distance are plotted dimensionlessly. The model was also tested using the man-made-trench data. Fig. 4 shows the comparison of the DGFEM model calculations starting from day 0 and the measurements of the trench evolution. The tunnel axis (Fig. 1) lies at x = 0.

Conclusion

Initial testing showed the model behaviour: increasing β_b leads to a skewer and faster moving ridge; increasing κ leads to the ridge becoming flatter. The DGFEM model could reasonably capture the evolution of the trench in the Paraná River for a period of 7 days. Including the correct hydrological data and updating bed levels at the boundary are needed to complete the comparison. To account for the contraction in width of the river where the measurement was taken the DGFEM model has been extended into two dimensions in the past year, including an unsteady numerical solution for the SWE by Tassi et al. (2007)

To use the model as a tool to prevent future tunnel disasters, the model could be used to simulate varying scenarios or combined with real time monitoring of water and bed-levels.

Acknowledgements

This work is the result of an MSc. research project conducted at the University of Twente and in part at the Universidad Nacional del Litorral in Santa Fe, Argentina. The author would like to thank Pablo Tassi, Sander Rhebergen, Onno Bokhove and Carlos Vionnet for their help in setting up the model.

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Influence of extreme flow conditions on the suspended matter quality of the river Meuse

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Abstract
Variations of heavy metal and organic micropollutant concentrations in suspended matter of the river Meuse were interpreted in order to assess the impact of extreme flow conditions on the suspended matter (SPM) quality. At low flow conditions the input of local point and diffuse sources mainly determines the contamination level of suspended matter. Lower contamination levels at the mouth of the river indicates upstream sedimentation of contaminated sediments and dilution with clean particulate material e.g. from tributaries. Resuspension of historically contaminated sediments becomes more important during high flow conditions, but can be counterbalanced by uptake of uncontaminated coarse material inside the river basin.

Introduction
Quality of river water and sediments have deteriorated as a consequence of intensive use of mining areas and production of synthetic materials. In the Netherlands, direct discharge of wastes into the river system was restricted and the general quality of Dutch rivers improved significantly since the 1970's (Middelkoop, 1998). However, most contaminants, like heavy metals and organic micropollutants, have a high affinity for the particulate phase. During high flow conditions, suspended particles will settle on the floodplains, leaving contaminated sediments behind (Bakker, 2006).
Recent changes in climate conditions indicate an increase of frequency and intensity of extreme flow conditions for rivers in the Netherlands and abroad. Previous research by Van Vliet (2006) showed a temporary deterioration of water quality during both droughts and floods of the river Meuse. The effects of extreme flow conditions on SPM quality is still not clear. This study discusses these effects for the river Meuse. Consideration of extreme conditions is required for an adequate analysis of the risks involved with poor quality of suspended matter and sediment in the river basin.

Methods
The SPM quality was investigated at two locations in the Dutch part of the Meuse. Eijsden (rkm 615) is located close to the Dutch/Belgian border and Keizersveer (rkm 855) close to the river mouth. SPM quality was considered in three situations:

1. <u>Seasonal variation of SPM quality</u>
   → assessing the temporal and spatial variation of SPM quality in the hydrological year 2001-2002.
2. <u>Variation of SPM quality during a drought</u>
   → comparing SPM composition during the drought of July-November 2003 with the same period in reference years 2002 and 2004.
3. <u>Variation of SPM quality during a flood</u>
   → variation of the SPM quality during the flood period of 1993. A unique dataset from two-hour sampling sequences was obtained.

Substances considered are heavy metals, polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) in suspended matter. These contaminants are known to have a high affinity for solid state materials such as sediments and suspended matter. For the flood of 1993 only data of heavy metals was available.

Seasonal variation of suspended matter quality
The hydrological year (April 1st to March 31st) 2001-2002 shows a distinct seasonal variation in discharge correlated with rain fall. Low flow conditions in the summer time cause a high input of algae (primary production) at location Eijsden. Contaminant concentrations are not clearly correlated with river discharge. The contamination degree mainly depends on variable input of point and diffuse sources along the river (Fig.1, example for copper concentrations). Downstream, the variation of the contamination degree decreases until reasonably stable levels are observed at Keizersveer, where also the input of primary production is absent. Generally, the contamination degree is much lower at Keizersveer, indicating sedimentation of contaminated particulate material in the upstream river bed and dilution with clean material, e.g. from tributaries.

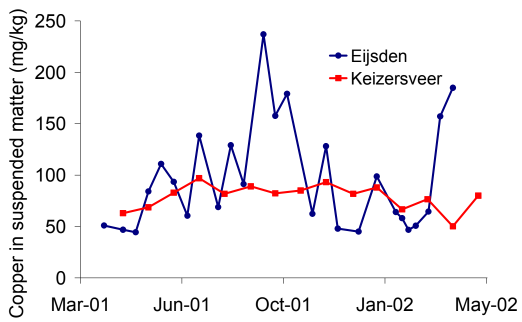

Figure 1: Seasonal variation of copper concentration in suspended matter of the hydrological year 2001-2002 at locations Eijsden (rkm 615) and Keizersveer (rkm 855) in the river Meuse.

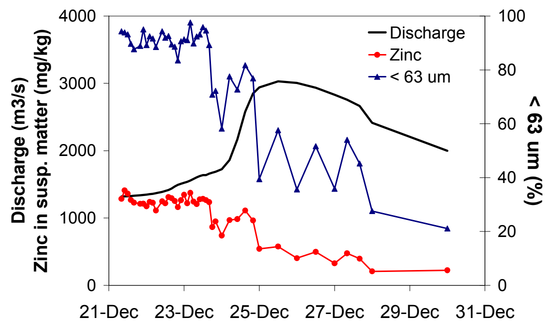

Figure 2: Discharge, zinc concentration and < 63 µm grain size fraction for suspended matter at location Keizersveer in the river Meuse during the flood of 1993.

Suspended matter quality during droughts

The drought of 2003 covers a period from July until November in which the discharge remains under 50 m^3/s. The SPM quality at Eijsden does not change significantly during the drought of 2003 compared to the reference periods of 2002 and 2004 (July-November). Only concentrations of PAHs in suspended matter are lower during the drought of 2003.

Suspended matter quality during floods

The complete rise and fall of the flood in 1993 was sampled only at location Keizersveer. A large shift of the grain size distribution before the peak of the flood illustrates a substantial input of uncontaminated coarse sand, leading to contamination levels which are 2 to 5 times lower than before (Fig. 2, example for zinc concentrations). Input of coarse material is preceded by a small increase of the contamination degree due to resuspension of contaminated river bed and floodplain sediment. The restricted dataset of location Eijsden does not show a substantial input of coarse material, so contamination levels remain more or less the same during the flood. It should be stressed, however, that the characteristics are different for every flood, leading to a variable contribution of recent and old clean and contaminated sediment sources in the suspended matter.

Conclusions and future perspectives

Recent changes in climate conditions mainly affect the SPM quality of the river Meuse during high flow conditions. Input from industrial, agricultural and domestic sources lead to a variable contaminant concentration during low and normal flow conditions. Resuspension of contaminated sediments becomes more important during high flow conditions, but is counterbalanced by uptake of uncontaminated coarse material inside the river basin. Especially the variable influence of extreme flow conditions on the spatial scale should be considered properly, as this has led to a heterogeneous distribution of contaminants in river bed and floodplain sediment. When these sediments are resuspended and transported, this may result in a substantial increase in ecological risks at downstream locations.

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A new approach to sand-silt mixtures in the morphologic modelling of lowland river systems

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Abstract
Existing operational morphological models cannot deal with the coexistence of sand and silt, which are subject to different transport mechanisms and complex interaction processes. Therefore we developed a new morphology module for the one-dimensional river modelling software SOBEK using a multi-fraction approach with interaction formulations as well as advection-diffusion algorithms for the fine, suspended sediment fractions. This has resulted in one of the most advanced one-dimensional modelling systems for lowland river morphology available at the moment. We applied the new morphology module to provide insight into the morphologic development of a large part of the Dutch Rhine delta.

Introduction
In large-scale morphological analyses of lowland river systems such as the Dutch Rhine delta a wide range of sediment diameters has to be considered. These different sediment fractions are subject to different transport processes. Furthermore lowland river systems are often characterized by the coexistence of sand and silt in the river bed, which influences the erodability and the bed composition in a special way. Until now, no morphologic model software has been presented, which is able to reproduce these complex processes.

Morphological modelling
Relevant processes
While coarse sediment is transported as bed load and mainly influences morphology in the upstream part of lowland river systems, fine sediment is transported as suspended material, i.e. it is moved by advection and diffusion processes in the water column. In the downstream part of lowland river systems, where flow velocities are low, sediment is exchanged between the river bed and the water column by deposition and resuspension. So in this area also the fine sediment significantly influences morphology. For the modelling of lowland river systems a good reproduction of these exchange processes is thus crucial. It also has to be considered that the resuspension fluxes are influenced by the type of material present in the river bed. If e.g. the clay content in a sandy river bed exceeds a certain limit the bed starts to behave as a cohesive material.

State of the art
Most existing models can neither represent the advection-diffusion character of the transport of suspended sediment nor deal with the division of sediment mixtures into a wide range of size fractions (multi-fraction approach).

The resuspension and deposition of sediment can be described by means of formulations derived by Galappatti (1983) for sand and by Krone (1962) and Partheniades (1962) for silt. However, these formulations do not include the complex interaction between sand and silt fractions in the river bed. Reference is made to e.g. Van Ledden (2003) for a mathematical description of this complex interaction, which is still a topic of ongoing research.

New approach
A new morphology module was programmed which includes all relevant morphological processes mentioned above. It was implemented into the 1D-modelling software SOBEK via the water quality package DelWAQ, which also allows for a direct coupling with water quality processes.

Model of the Dutch Rhine delta
The new morphology module was first used to model the Dutch Rhine delta (Fig. 1). At the upstream boundary discharge hydrographs are imposed which also transport suspended sediment into the system. The downstream boundary is influenced by tidal water levels. Four sediment fractions are defined in the river bed, two of which are also present in the water column. Since a 1D-model cannot calculate the sediment distribution into bifurcating branches itself, distribution relations are specified at each bifurcation. Morphological simulations were carried out for a period of 10 years.

Although the model has undergone only a rough hydraulic calibration and no morphologic calibration, the morphologic characteristics and the development of the river system are reproduced in a realistic way. Fig. 2 shows the content of the finest sediment fraction in the bed.

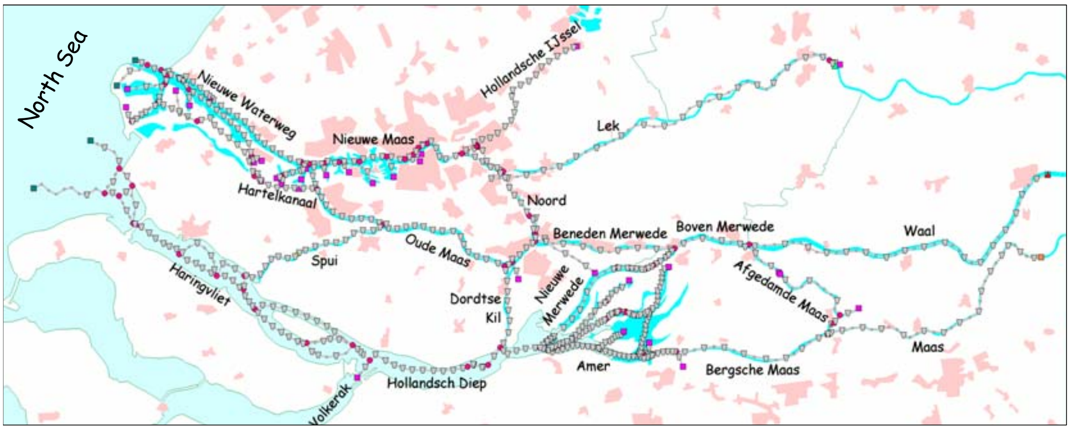

Figure 1. Spatial discretisation of the model of the Dutch Rhine delta.

The red and orange colours indicate a high percentage of fine sediment, while in the blue branches hardly any fine sediment is present in the river bed. The transition between the two regions is rather abrupt and located downstream of the confluence of Amer and Nieuwe Merwede (red circle). This corresponds well to measurement results.

The model results also stress that in the downstream part of the system the exchange of sediment between the river bed and the water column is an important process. Due to the interaction of river discharge and tidal influences the system constantly changes between states of erosion and deposition as well as equilibrium states.

Fig. 3 shows the modelled bed level change in a part of the delta after 10 years. The figure includes the bifurcation of the Boven Merwede into Nieuwe and Beneden Merwede. In the Beneden Merwede, just downstream of this bifurcation, a deep erosion pit develops which is not observed in reality. In the model too little sediment moves across the bifurcation into that river branch because of an incorrect sediment distribution relation. This reveals how important it is to find good distribution relations at all bifurcations.

Conclusions

The new morphology module is a promising tool that helps to gain a more profound insight into morphological processes in lowland river systems. The application to the Dutch Rhine delta has underscored the importance of reliable relations for the distribution of sediment at bifurcations, and that further research concerning the interaction between sand and silt fractions in the river bed is needed.

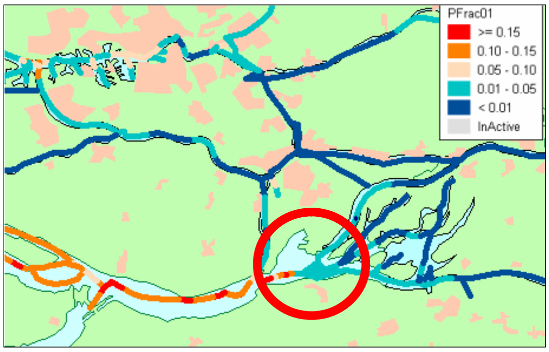

Figure 2. Content of finest sediment fraction (1µm-8µm) in the river bed as percentage [-].

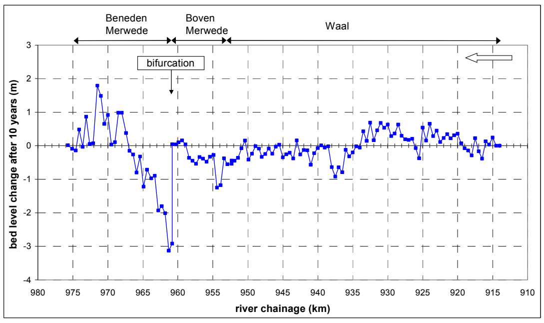

Figure 3. Bed level change around the bifurcation of the Merwedes after 10 years including dredging activities.

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Long-term evolution of meandering channels with adjusting widths downstream of a bifurcation

winner of the NCR-days presentation Award 2007

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Abstract
A 1D morphodynamic model for the development of the bifurcation and bifurcates is presented and applied to the last major apex avulsion of the Rhine delta initiated 2500 years ago. The occurrence of meander bends just upstream of the bifurcation, adaptating channel width and gradient advantage together determine over what period an initially avulsed bifurcate develops into a major new branch.

Introduction
The aim is to assess what factors determined the duration of the Nederrijn-Waal avulsion; that is, the time between the initiation of the ancestral Waal courses and the moment when nine-tenths of the Rhine discharge was conveyed through the Waal (after which the Pannerdensch Kanaal was dug). First the case study is presented based on historical and geological studies. Then a model is used to assess how various processes affect the time-evolution of discharge division.

Case study: Nederrijn-Waal avulsion
The geological reconstruction of the Rhine branches is entirely based on the data and interpretation collected in Berendsen and Stouthamer (2000) and further detailed in Stouthamer (2005). The historical information is derived from Van de Ven (1976) and from 20 original historical maps drawn between 1595 AD and 1805 AD.

During the past three millennia the river Rhine had two main courses to the North Sea. The first and oldest main course is Rhine, Nederrijn, Kromme Rijn and Oude Rijn into the estuary at Leiden. Later avulsions diverted some flow into the Gelderse IJssel and into the Lek and Hollandse IJssel.

The second course avulsed from the Rhine at Lobith over a period of the last few centuries BC. This course remained of minor importance until about two millennia ago. Several parallel channels existed, including the Linge, which avulsed into the present course of the Waal in 325 AD. After that time the Waal became more important. By the 12th century the Leiden estuary had silted up and the Kromme Rijn and Hollandse IJssel were dammed. The Lek growed but had not increased to the same size as the Linge and Waal, indicating an increasing discharge through the Waal system. The effect of the St Elisabeth inundations on the Waal was negligible (Kleinhans et al. 2007a).

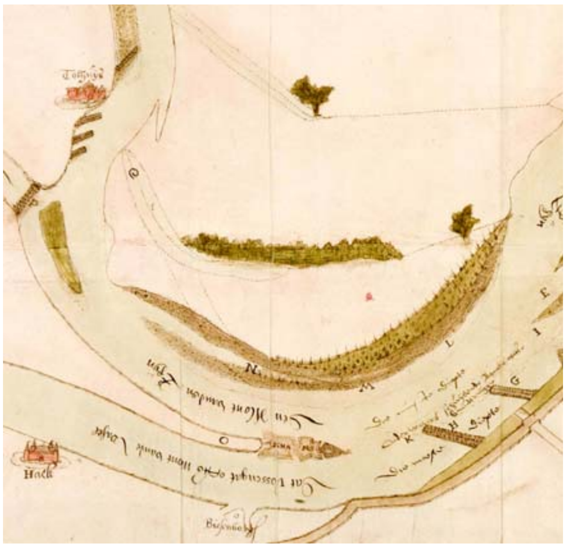

Figure 1. Fragment of 1595 map at the Schenkenschans bifurcation, showing equal widths of Waal and Nederrijn. Source: RA Gelderland 297. North is to upper left corner.

The oldest available map of the bifurcation (1595 AD) shows the Nederrijn and Waal with equal channel width; both narrower than the upstream Rhine (Fig.1). A bend initially favoured the Nederrijn with relatively more water and less sediment, but a cutoff through the Vossegat reversed the upstream bend direction. As shown on subsequent maps a meander at Schenkenschans migrated downstream such that it favoured the Waal with more water. The width and depth of the Nederrijn decreased while the width of the Waal increased. Around 1700 AD, about two millennia after the ancestral 'Waal' course was formed, the Waal conveyed about nine-tenths of the discharge.

Modelling
Model setup
A simple 1D research model was built for efficient morphodynamic computations for a period of 2500 years. Two branches are connected to the upstream river at a nodal point, where the flow and sediment is divided. The nodal point relation is validated on Delft3D model runs (Kleinhans et al. 2006). The model accounts for a gradient difference between the bifurcates, effects of a meander bend just upstream of the bifurcation, and adjusting channel widths due to changing discharge.

An upstream meander favours one bifurcate with more sediment due to spiral flow and the other with more water as a function of bend radius. This effect is counteracted by the transverse slope, which deflects the sediment transport to the deeper part of the channel.

The width adaptation is simulated by relaxation to an equilibrium width, which is a function of discharge (hydraulic geometry relation calibrated on the Rhine). The time-scale of width adaptation depends on the bed sediment transport rate at that location and bank plus bed sediment mass is conserved.

The length of the Nederrijn and Waal to the North Sea (gradient), the size of the upstream meander bends (radius, initial channel widths and sea level rise or basin subsidence scenarios were derived from historical and geological data.

Modelled bifurcate evolution

The evolution of the bifurcates is mostly determined by the upstream bend and to some extent by a gradient advantage (Fig.2). The width adaptation in the bifurcates slows the evolution very much (Fig.2). Tectonics, subsidence and sea level change do not affect the bifurcate evolution (but did affect the avulsion locations according to avulsion literature). Stable symmetrical bifurcations only occur for exactly equal bifurcate conditions. Note that the present Pannerdensch Kanaal bifurcation was stabilised by bank protection soon after it was dug (van de Ven, 1976) and by bed armouring (Kleinhans et al. 2007b). The old channel becomes a residual channel conveying flood water but no sand in agreement with observations.

A new result is that switching bends or migrating sinusoidal bends (Fig.3), on average accelerate the evolution. The time between the initiation of the bifurcation and the modelled equilibrium condition varies an order of magnitude depending on the river bend dimensions, migration rate and its initial phase upstream of the bifurcation and on the gradient advantage. The fixed bend and migrating bend scenarios bracket the real case in agreement with observations of bend migration and bifurcation position. The migrating bend model suggests that the Waal enlarges in jumps which could explain historical records of sudden complaints about navigability of the Nederrijn and Gelderse IJssel.

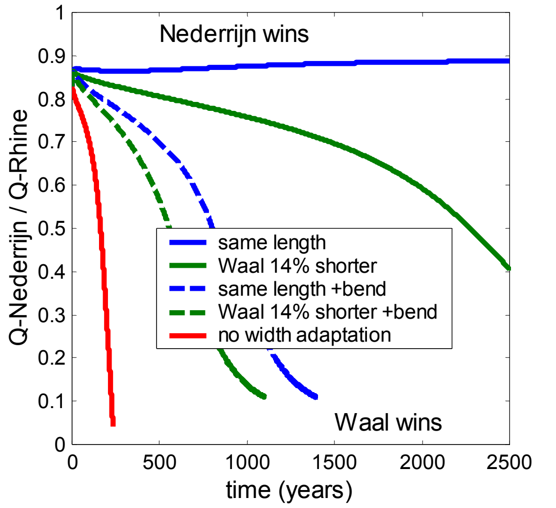

Figure 2. Effects on discharge division of gradient and/or a fixed bend upstream of the bifurcation, and of (no) width adaptation.

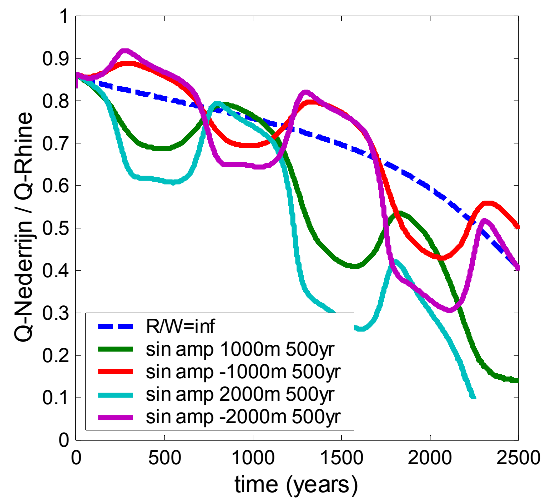

Figure 3. Effect of migrating sinusoidal meanders at bifurcation. Amplitude and half-period given; wave length 8 km, positive amplitude means Waal initially connected to outer bend. Dashed line indicates case without bend (but with gradient advantage).

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Measuring tidal discharge in a river bend using a horizontal acoustic Doppler current profiler

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Abstract
Horizontally mounted acoustic Doppler current profilers (ADCPs) measure array data of velocity along three acoustic beams in a horizontal plane. This data can potentially yield accurate discharge measurements, provided that sufficient knowledge about the structure of the flow is available to interpolate and extrapolate local velocities over the cross-section. This research takes a first step in the development of a technique to integrate knowledge on curved flow with HADCP measurements to obtain discharge information. A depth-averaged model is presented in which momentum transport of secondary flow is included through a closure submodel. The model is an improvement to the work by Kalkwijk and de Vriend (1980) in that it can easily be extended for sharply curving channels and it is more stable. The model has been applied to a meander in a tidal reach of the River Berau, (East-Kalimantan, Indonesia). The computational results are compared with field measurements, showing a fair agreement during ebb tide in the inner bend. In the outer bend, however, an additional weaker peak is observed that may relate to width variations. It is foreseen that an optimization procedure can be designed to calibrate the model with field measurements in order to obtain discharge measurements.

Introduction
Horizontal acoustic Doppler current profilers (HADCP) can measure array data of velocity with high spatial and temporal resolution, allowing to obtain discharge estimates when enough knowledge of the local flow structure is available. The HADCP employed in this study was installed in a meander bend of the river Berau (see Fig. 1). To convert the HADCP data to discharge, in-depth knowledge of flow characteristics in a tidal river bend was required, which was provided by ship borne measurements and modelling.

Field study
The considered river bend was surveyed with 1.2 MHz ADCP mounted down looking from a vessel. This vessel navigated transects orthogonal to the river axis during a semi-diurnal tidal cycle, to obtain flow measurements to build the theory to extrapolate the HADCP data. Depth soundings were taken over the whole bend to understand flow characteristics and to feed the model.

Figure1. River bend under consideration. (Source: Google Earth)

Flow model
Flow in river bends usually features secondary flow induced by centrifugal force and bottom friction. To understand the local flow conditions and to extrapolate HADP velocity data to the whole cross-section a flow model is developed. A simple model was chosen to enable to use it in an optimization routine to fit the model on the measurements. The model is based on the work of Kalkwijk and De Vriend (1980). It is a depth averaged model that includes a parameterisation of secondary flow. Secondary flow is parameterised by decomposing transverse flow in a depth-averaged bathymetry induced part and a curvature induced part. The latter is included through a parameterisation of local flow conditions, obtained solving a vertical momentum balance given a profile for longitudinal flow velocity. The present model was developed in such a way that it can be extended in the future to include width-variation, parameterisation of non-linear feedback mechanisms for sharp bends (Blanckaert and De Vriend, 2003) and lag effects in the adaptation of the flow to curvature.

Results

The flow model was compared with the case investigated by Kalkwijk and De Vriend yielding similar results (see Fig. 2). Some differences are probably caused by small differences in the bathymetry.

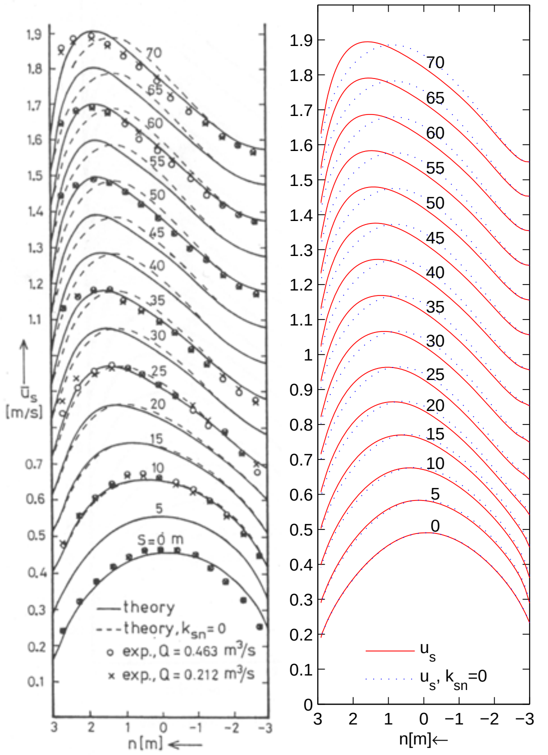

Figure 2. Comparison between the original model(left) and the present one.Due to momentum transport by secondary circulation the peak of longitudinal velocity u_s moves to the outer bend (positive n-direction).

Comparison of the measured data with the model results (see Fig. 3) shows a fair agreement. It may seem surprising to have the modelled velocity peak on the inner bend, but this is caused by higher longitudinal gradients in the inception of the inner bend. This higher gradient is the result of the transverse surface slope that counteracts the imbalance between centrifugal force and secondary circulation. The difference between the vessel mounted ADCP (VMADCP) and HADCP data is caused by the different depth levels at which the data was obtained. The measured velocities feature two peaks: one near the outer bend and a smaller one close to the inner bend. Discrepancies between measured and modelled results are partly caused by the limited accuracy of the bathymetry data.

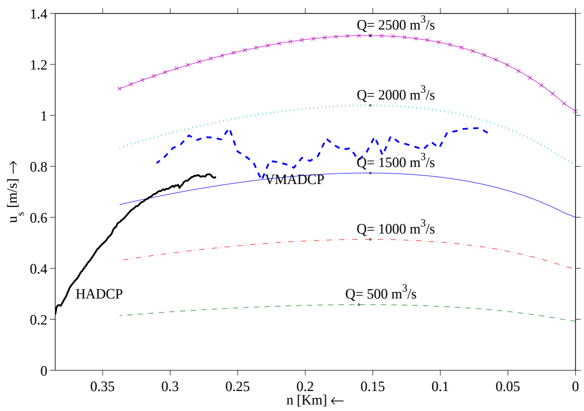

Figure 3. Measured profile of longitudinal velocity and modeled velocities for various discharges.

Conclusions

The model reproduces the measured flow patterns fairly well, but has to be improved to use it for the conversion of HADCP data to discharge estimates. The double peak in the measured longitudinal velocity is likely caused by the width variations at the entrance of the bend. These width variations cause two secondary circulations to develop. These secondary circulations decrease bottom shear stress where flow is in upward direction and increase it for downflow (Nezu and Nakagawa, 1993). An accurate, detailed bathymetry is essential to properly simulate shallow water flows and thus also to obtain accurate discharge estimates from HADCP data. It is foreseen that, with a simple model capable of describing the flow within the required accuracy, the HADCP will prove to be a powerful instrument for continuous discharge measurements.

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The sedimentary dynamics of embanked floodplains

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Abstract
Goal of the presented research is to get insight into the spatial variability of the floodplain sediments, and the processes causing this variability by (1) setting up a database of the spatial variability of the floodplain sediments along the river Rhine, and (2) reconstructing the sedimentary dynamics since normalisation.

The database is compiled of existing data about the lithology, the morphology, and the sediment characteristics, that are visualized in lithological profiles and thematic maps.

Reconstructing the sedimentary dynamics involves an assessment of sedimentation rates with three different methods: (1) ^{137}Cs-dating, which relies on correlation of peaks in a vertical soil profile to peak years of ^{137}Cs deposition, (2) OSL-dating, which uses the accumulated charge that is trapped in quartz minerals that are shielded from the light as a measure for burial time, and (3) heavy metal analyses, which enable to relate the varying metal contents in a vertical soil profile to the known pollution history.

Introduction
Future measures in the embanked floodplains of the Netherlands aim at the enhancement of the discharge capacity and the improvement of the ecological quality, and include mining of clay, sand and gravel. The efficiency and sustainability of such measures are strongly dependent on the sedimentary dynamics, which most importantly involves sedimentation and erosion processes causing spatial variability of floodplain sediments. Therefore, it is of importance to get insight into this variability and associated processes.

The presented research focuses on (1) mapping the spatial variability of the floodplain sediments along the river Rhine (database development), and (2) reconstruction of the sedimentary dynamics since normalization (assessment of sedimentation rates).

Database of the embanked floodplains in the middle Waal
In a database, existing data of the middle Waal (reach Nijmegen-Tiel) are compiled, about the lithological structure, the morphological development and the spatial distribution of sediment characteristics. The information is derived from TNO, Alterra and Utrecht University databases, and is visualized as lithological profiles and thematic maps (Fig. 1). The data will be used to reconstruct historical sedimentary dynamics, and may serve to select optimum locations for ecological rehabilitation or mining projects.

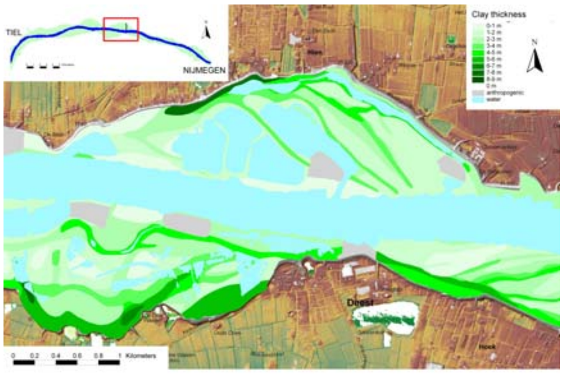

Figure 1. Map of the clay thickness in the Hiensche Uiterwaard, which is one of the thematic maps in the database of the middle Waal (Hebinck, in prep.).

Reconstructing sedimentation rates
In previous research by Maas et al. (2003) 15 cores were taken from three different undisturbed floodplains along the river Rhine (Fig. 2). The sedimentation rate was calculated using ^{137}Cs-dating. In the present project, two other methods are being applied to calculate the sedimentation rates in addition. These analyses are in process.

^{137}Cs-dating
The anthropogenic radionuclide ^{137}Cs entered the atmosphere as a result of nuclear bomb tests around 1960 AD and the Chernobyl accident in 1986 AD. Subsequently, it was deposited on the floodplains by atmospheric fallout and by deposition of fine suspended sediments to which it is bound. A vertical activity profile of a soil core can be measured by the PHAROS device (Rigollet en De Meijer, 2002) (Fig. 3). Peaks in activity correspond to the floodplain surfaces of 1960 AD and 1986 AD, and hence average sedimentation rates can be calculated.

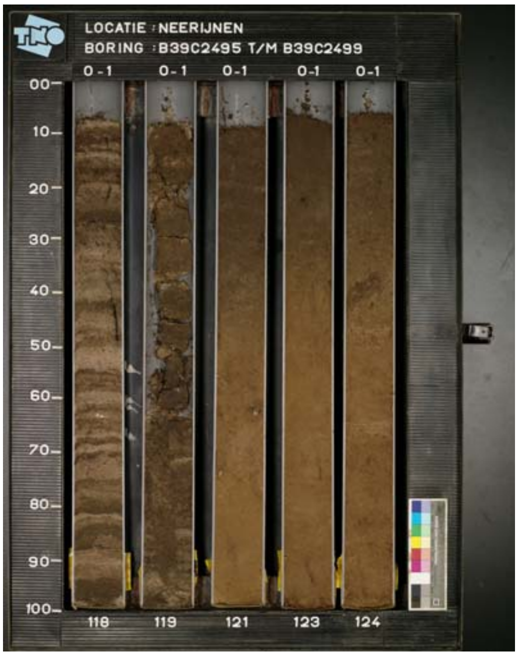

Figure 2. Undisturbed sediment cores from the Neerijnen embanked floodplain.

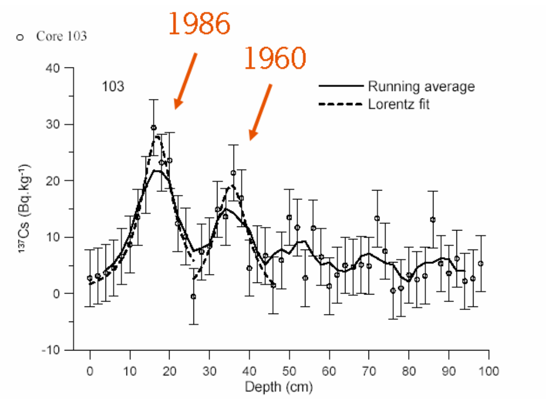

Figure 3. Peaks in ^{137}Cs concentration can be recognized in the activity profile of a soil core, and correspond to the surface in the peak years of atmospheric ^{137}Cs deposition (Maas et al., 2003).

OSL-dating

Optically Stimulated Luminescence (OSL) dating is a relatively new technique that makes use of the charge that is trapped in quartz- and feldspar minerals by natural ionising radiation from the environment. The charge acts as a clock that starts to count when a particle is deposited and shielded from light. When the particle is exposed to light again, it releases its charge and the clock is set to zero. Hence the accumulated charge is a measure for the burial time of the particle. When both the released charge and the ionising radiation from the environment are measured, the age of fluvial deposits can be calculated (Wallinga, 2001).

Heavy metal analysis

Heavy metals are occurring naturally in river waters. Since approximately 1860 AD however, urban and industrial activities led to a significant increase in the heavy metal concentration of the Rhine water. In the water, heavy metals are bound to the fine suspended sediment particles, and enter the floodplain during flooding events. The amount of heavy metal pollution has varied in history (Fig. 4). Comparison of a vertical profile of heavy metal contents in a soil core with the known pollution history enables the calculation of sedimentation rates (Middelkoop, 1997).

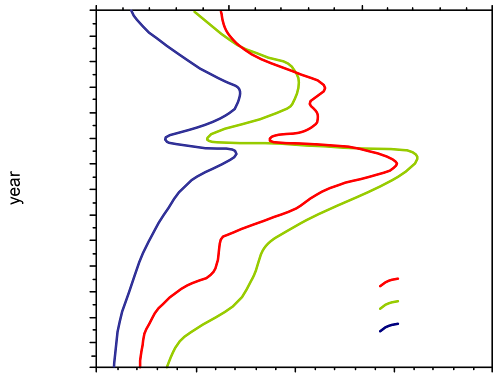

Figure 4. History of heavy metal pollution in the river Rhine. Pollution started to increase around 1860 AD and reached a maximum in the 1930s. After a temporary decrease during WW II a new peak was reached in the 1960s, followed by a strong decrease in the 1970s as a result of the Rhine Action Plan (after Middelkoop, 2000).

Acknowledgements

This research is funded by the Delft Cluster project ‘safety against flooding’.

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Errors in bottom-tracking of acoustic Doppler current profilers

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Abstract
Acoustic Doppler current profilers (ADCPs) are increasingly being used for discharge measurements, as they allow to measure flow velocity non-intrusively, at a high resolution in time and space. ADCPs are often employed from a vessel, which requires correcting measured velocity for movements of the vessel. This is achieved with a technique called bottom-tracking (BT) that determines the vessel velocity relative to the river bottom. A known problem of this technique is the error it introduces when applied on a river with a high bedload transport rate. This causes errors in discharge measurements, but from another viewpoint could be an opportunity to determine bedload transport rates. Based on a theoretical study of the acoustics of bottom tracking and ADCP measurements on the Merwede bifurcation (Netherlands) this study aims to determine possible sources of bottom-tracking errors and to investigate the suitability of the errors to quantify bedload transport. An improper ADCP-compass calibration appears to be the primary source of bottom-tracking error. In general, a poor correlation was found with bedload transport rates, but under some conditions bottom track error seems to be dependent on cross-section averaged flow velocity.

Introduction
Detailed discharge measurements nowadays mainly rely on measurements with ADCPs employed downward looking from vessels. These instruments determine the vessel-velocity using a technique called bottom-tracking (BT). This technique is known to make errors on locations with high bedload transport rate (see Fig. 1). This bias in combination with DGPS (differential global positioning system)

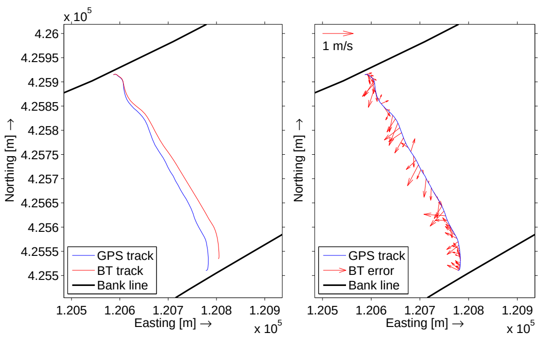

Figure 1. Bias in BT (left) and error vectors (right)

was used by Rennie et al. (2002) to determine bedload transport rates. This study aims at understanding error-sources in bottom tracking both from a theoretical study of the underlying acoustics and an analysis of field measurements.

Bottom-tracking acoustics
The underwater acoustics and their suitability to determine sediment concentrations and size distribution throughout the water column have been thoroughly analysed by Thorne and Campbell (1992), and in subsequent papers by those others. They show that the response of an acoustic signal to a suspension of scatterers features, for small sediment particles, an almost linear increase with the median of the particle size distribution (D_{50}) and for larger particles it remains almost constant (see Fig. 2).

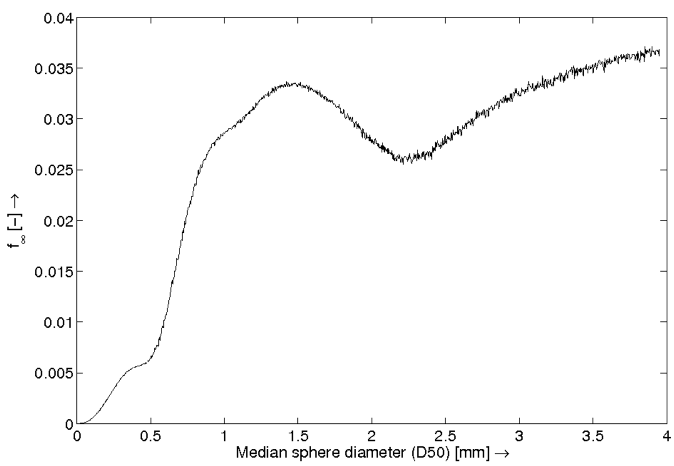

Figure 2. Acoustic response (form function) for suspensions of spheres (Acoustic properties of RDI Workhorse 1200 KHz ADCP)

Sediment particles in the water column will also attenuate the acoustic signal. This attenuation depends on the D_{50} in a similar way as the scattering, and is proportional to the square of the mass concentration. Given a typical sediment profile (e.g. Rouse profile) it is possible to determine the attenuation of the signal through the water column (see Fig.3).

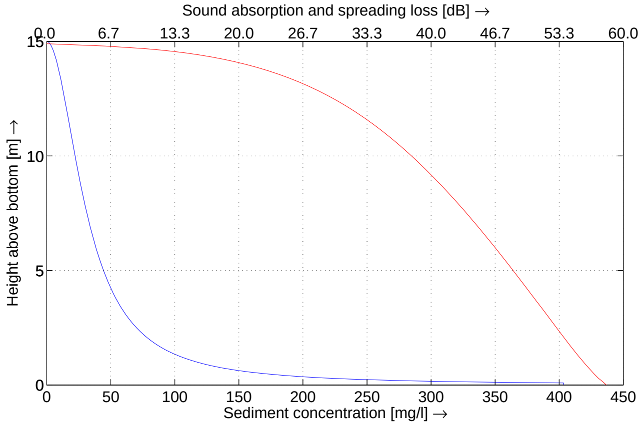

Figure 3. Spreading and absorption losses for a typical sediment profile (Uniform sediment, D50=200µm)

Field measurements

The present study focuses on data collected on the upstream branch of the Merwede bifurcation (Frings, 2005). This bifurcation is a freshwater tidally influenced bifurcation. ADCP and DGPS data were combined to determine the bias in the BT velocity. This bias clearly is dependent on the direction of the measured transect and strongly correlates with the vessel heading as can be seen in Fig. 4

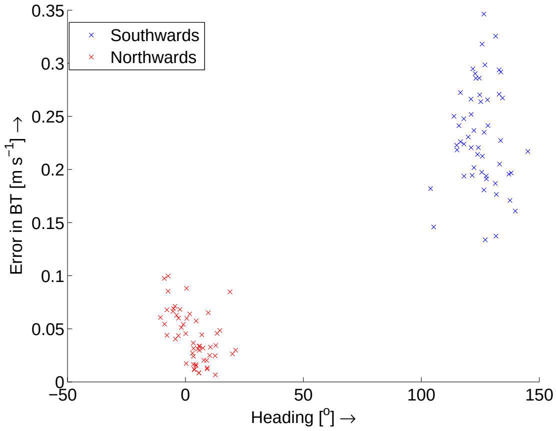

Figure 4. Transect averaged BT error for each transect. The error in BT clearly correlates with the heading

To determine the correlation of the BT error with bedload transport rates, the data was clustered in heading classes and for each class the correlation between cross-section averaged flow velocity and BT error was determined. The results show that the BT error correlates with the averaged velocity only for northward transects (see Fig. 5).

Conclusions

The data clearly shows that a compass calibration is needed to minimize error in BT. This error can be of the same order of magnitude as the bedload transport induced bias, or even higher.

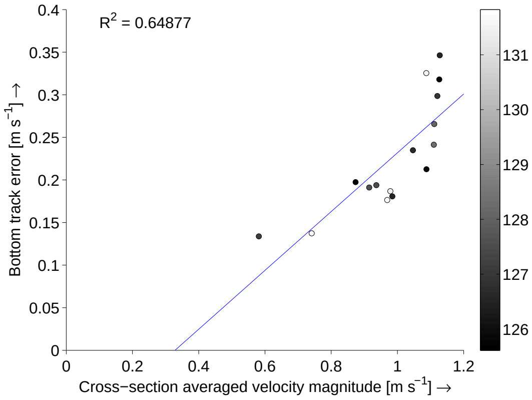

Figure 5. Correlation of cross-section averaged velocity and BT error for a northward transect in one heading class

The low correlation of cross-sectional averaged velocity with BT error for southward transects can be explained by the high heading bias that may counterbalance the error induced by bedload velocity. Trump and Marmorino (1997) use the diffence between DGPS and BT velocity to calibrate the compass in post-processing. This method, however, assumes no other bias than heading-induced. Temporal and spatial variation in bedload velocities (Hamamori,1962) renders it difficult to use BT error as a stand alone technique for bedload transport measurements. However, provided that the compass is properly calibrated, the ADCP in combination with a DGPS can be used to gain insight in the spatial distribution of bedload velocitiy and bedload transport and should always be sided with conventional measurements.

Acknowledgements

Thanks to AquaVision for their advice on technical issues and to Roy Frings and Maarten Kleinhans for sharing advice and experience from the measuring campaign.

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Bed roughness under partial transport conditions

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Abstract
Reliable roughness models are of great importance, for example when predicting water levels in rivers. However, classical roughness models, based on fully mobile sediment beds, are not adequate for conditions in which only part of the bed is mobile (partial transport). New flume experiments demonstrate that bed roughness is strongly influenced by the volume of available mobile sand. To improve roughness models, the volume of available mobile sand should be taken into account.

Introduction
Classical roughness models are based on fully mobile sediment bed rivers (Engelund and co-author, 1967; White et al., 1980). However, it is known that in sand-gravel bed rivers, sand may be mobile while the gravel is not. This is called *partial transport* (Wilcock and co-author, 1997; Kleinhans, 2002).

Earlier experiments (Van der Zwaard, 1974) showed that bed roughness under partial transport conditions is related to the sediment transport rate. A theoretical model was developed to describe these observations.

To improve future models, it is necessary to test the extent to which roughness models (Engelund and co-author, 1967; White et al., 1980; Van der Zwaard, 1974) describe bed roughness under partial transport conditions. For this, a new series of laboratory experiments were executed to further study the bed roughness and the processes affecting the bed roughness under partial transport conditions.

Experiments
Experiments were executed in a flume (7 m x 0.3 m) in which a coarse gravel bed (D_{50}=13.4 mm) was installed under a predefined slope. Sand (D_{50} =0.83 mm) was fed in gradually until the complete coarse bed was covered with sand. Under the imposed flow conditions (bed shear stress ~ 1.5-2.1 Nm^{-2}), the sand was mobile and the gravel was not. The sand was recirculated and the sediment transport rate S was measured. The bed roughness height $k_{s,b}$ was derived from the measured water depth and energy slope. Bed surface images were analyzed to measure the relative area of the bed surface covered by sand. The volume of available sand on top of the gravel bed V and dune dimensions were derived from detailed bed level profiles measured with a laser system.

Results
The bed roughness was analyzed as a function of the sand covered surface, the sediment transport rate and the sand volume. The sand volume was found to be a suitable parameter to describe the behavior of bed roughness under partial transport conditions. Figure 1 shows the bed roughness as a function of the relative sand volume V^*. The relative sand volume is defined as:

$$V^* = V / V_0$$

V_0 is the sand volume in the case of the bed surface being completely covered with sand (alluvial bed). For $0 < V^* < 1$, there is a limited availability of mobile sand (supply limitation).

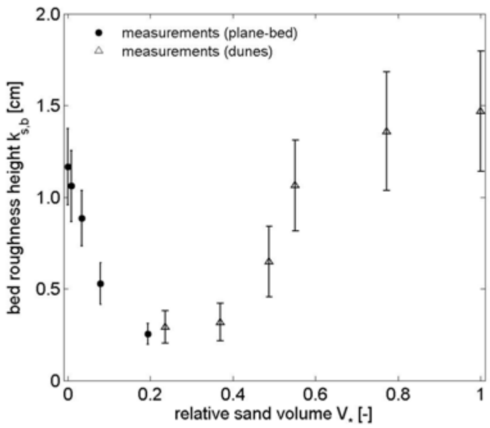

Figure 1: Bed roughness height as a function of the relative sand volume.

For small value of V^* in Fig. 1, the bed roughness decreases for increasing V^* as sand fills in the pores of the coarse layer. For large V^*, the bed roughness increases for increasing V^* as sand dunes develop. The sand dunes reached maximum dimensions for V^* = 1.

Model predictions
The Engelund and Hansen model (1967) is based on integral parameters describing the flow and the bed. The model predictions are compared with the measurements (see Fig. 2).

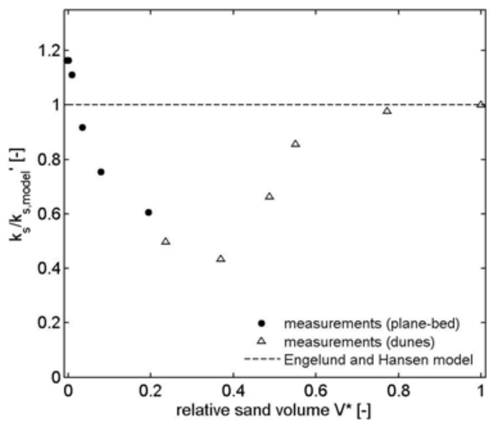

Figure 2: EH-model. The ratio between measured bed roughness $k_{s,b}$ and (calibrated) predicted roughness $k_{s,model}$' is given as a function of the relative sand volume. The predicted roughness $k_{s,model}$ is calibrated for V = 1 (alluvial bed).*

This model does not describe the observed behavior of the bed roughness for V* < 1.

The Van der Zwaard model (1974) describes bed roughness as a function of the relative sediment transport rate (see Fig. 3). The relative sediment transport rate is defined as:

$$S^* = S / S_0$$

S_0 is the sediment transport rate under full mobility conditions (alluvial bed).

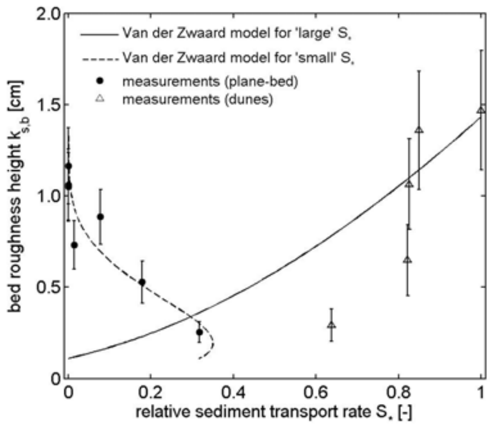

Figure 3: Van der Zwaard model. The predicted roughness and measured roughness are given as a function of the relative sediment transport rate.

This model distinguishes two parts: (1) for small values of *S**, the model is in line with the observations, (2) for large values of *S**, dunes contribute to the bed roughness, resulting in a bed roughness increase for increasing *S**.

Conclusions & recommendations

The bed roughness under partial transport conditions is strongly influenced by the volume of available mobile sand *V**. For small value of *V**, the bed roughness decreases with increasing *V** as sand fills in the pores of the coarse layer. For large values of *V**, dunes develop and the roughness increases with increasing *V**.

Classical roughness models (e.g. Engelund and co-author, 1967; White et al., 1980) are based on full mobility conditions and are not adequate for supply-limited conditions. The Van der Zwaard model (1974), which takes into account the sediment transport rate, shows similar trends as observed in the experiments. However, from this experiment it became clear that the sand volume is probably a better parameter than the sediment transport rate when measuring the supply limitation. Future roughness models could be improved if the sand volume is taken into account.

Acknowledgements

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Recent Detection Techniques for Wide Scale Surveys on Rivers

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Abstract
Attention for sustainable rivers has increased considerably over the recent years. In order to feed ongoing research more and more reliable data of the current state of the rivers are needed. As the capabilities of detection techniques for wide scale coverage have increased significantly in the past decade the current state of rivers can be determined more accurately and with less effort.
Two relatively new detection methods were used to determine the state of the riverbed: 1) the bathymetry (up to the waterline) and bed characteristics (such as silt, sand and rock amour) of an underwater embankment near Tiel (Figure 1) were determined with interferiometric multibeam and side scan sonar (Geoswath Plus)
2) the bottom stratification around a barrage near Sambeek (Figure 1) was determined with an underwater ground penetrating radar (Zond 12E).

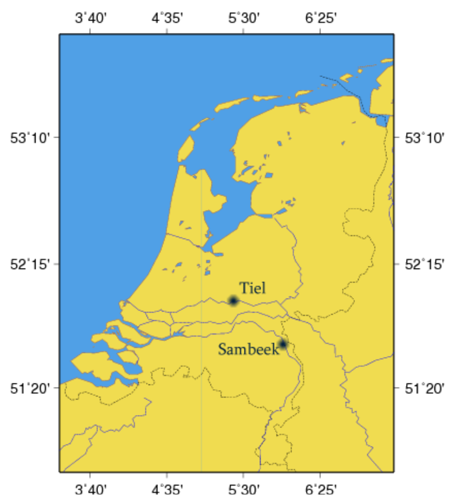

Figure 1: Overview of the selected test locations along the River Waal and de River Meuse

Introduction
The expected climate changes will have a lasting effect on the river climates in the Netherlands. Much research is put in finding ways to deal with the predicted increasing run-off. Knowledge of the current state of the river and its surrounding protective bodies are a starting point for this research. New detection equipment allows for better evaluation of the underwater body of the river.

Recent detection techniques
Interferiometric multibeam
Since the development of multibeam echosounders (i.e. multibeams, MB's) in the seventies two types have emerged: beam forming and interferiometric (or phase measureing) MB's (Lurton, 2002). Beam forming MB's have been predominantly in use since the eighties due too low reliability and accuracy of the interferiometric multibeam.
Recent advances in interferiometric technology has largely closed the gap between the two systems (Gostnell, 2005, Gostnell et al., 2006). The large swath width (maximal 20 times the water depth) and swath angle (greater than 180 degrees) of the Geoswath Plus enable a complete survey of the bathymetry up to the waterline. Although the latter is also possible with existing MB's i.e. tilting the multibeam, similtaneous surveying of the embankment up to the waterline and the bottom by the interferiometric MB produces reliable, accurate and cost efficient measurements.
An additional advantage of the interferiometric MB is the integration of the side scan sonar (SSS). Although SSS's have been in use widely since the eighties adequate interpretation of the data has been hampered by the lack of accurate depth information in the data. The interferiometric MB measures both the intensity and origin of all received acoustic signals enabling detailed analyses such as habitat mapping and bottom characterisation

Underwater ground penetration radar
The ground penetrating radar (GPR) has been in use since the seventies as a predominantly land based profiling technique (Olhoeft, 1984) until the recent introduction of underwater antenaes. Underwater GPR (UGPR) provides better contrasts compared to other surveying systems such as subbottom profilers.
The measurements provide information about the stratification and location of buried objects and man made structures. The consistency of the antennae-water coupling and the accuracy of the determination of the wave propagation velocity allows for reliable data interpretation. The penetration of over 2 m and a resolution of about 10 cm matches the requirement of many applications.

Results

Underwater embankment survey near Tiel

An underwater embankment with rock armour protection was surveyed near the Bernardsluizen in Tiel. The survey included both MB and SSS measurements. For ground truthing of the interpretation (soil type, surface relief) the bottom was inspected by divers. The bathymetry measurements (Figure 2) show good results as the embankment is measured up to the waterline. Figure 3 shows the results of the bottom classification. Both the SSS data and bottom classification results show ample results as the transition (indicated with the blue line) from rock armour to silt (clearly observed by divers) is hardly visible.

Underwater survey near Sambeek barrage

The downstream side of the barrage on the River Meuse near Sambeek was surveyed with the UGPR to investigate the rock armour and subbottom profile. Figure 4 shows results of the survey (middle of the river). The measurements show a distinct layer of rock armour of about 1 meter thickness and a concrete slab. No other significant reflectionsl are observed below the rock armour

Conclusion

The bathymetry results of the interferiometric multibeam are accurate and useful as the underwater embankments are measured up to the waterline in one survey line.
The SSS results on however are less clear. Although dive inspections show a clear line between the rock surface and silt surface no clear borderline has been detected with the side scan sonar. Several software packages were used (see references list) for the bottom classification, but none show satisfactory results. A clear explanation has not yet been found. One reason could be the large size of the rock armour (d_{90}>15 cm) which is not normally covered by the classification software. Additional research is required.
The UGPR results show no other layer interfaces below the rock armour at the Sambeek barrage. Survey lines outside the area of investigation show a similar absence of stratification.
UGPR surveys also prove to be a useful technique that supports the interpretation of the SSS data. It can help to explain features observed in the SSS data provided the top layer is significantly thick. As a stand-alone survey it is useful for detecting buried objects and rock armour.

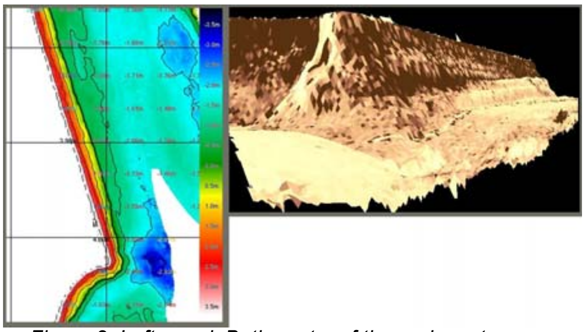

Figure 2: Left panel: Bathymetry of the underwater embankment up to the waterline. Right panel: side view with draped SSS results

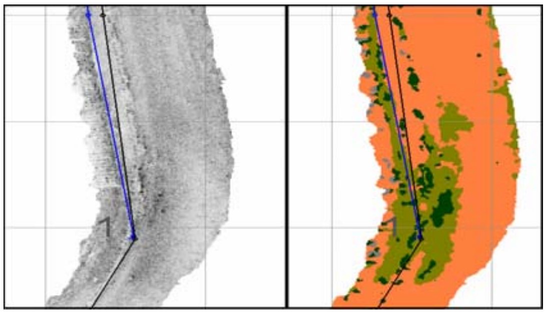

Figure 3: Determination of the bottom characteristics: SSS (left panel) and bottom classification results (right panel).. Borderline silt-rockarmour on the surface indicated by blue line, end of rockarmour underground indicated by black line.

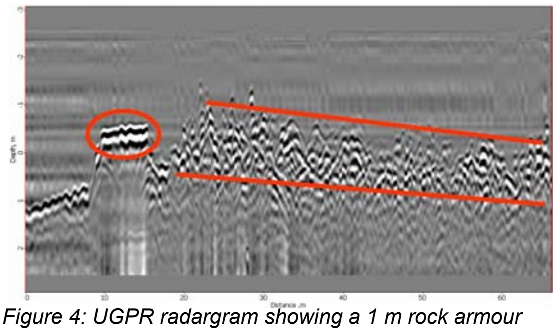

Figure 4: UGPR radargram showing a 1 m rock armour layer and a concrete slab in the River Meuse.

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Olhoeft, G.R., 1984, Applications and limitations of ground penetrating radar, [Expanded abstracts]: Society of Exploration Geophysicists, 54th Annual International Meeting and Exposition, Atlanta, GA, p. 147-148.

Software:

Geotexture, GeoAcoustics Limited, ww.geoacoustics.com

QTS Sideview, Quester Tangent, ww.questertangent.com

MB-System, Caress, D. W. and Chaye, D. N., Lamont Doherty Earth Observatory, Colombia University, www.ldeo.columbia.edu/MB-System

Scan, Groundtracer BV, www.groundtracer.com

Prism, Radsys, www.radsys.lt

Modelling dynamic roughness during floods

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Abstract
In this paper, we present a dynamic roughness model to predict water levels during floods. Hysteresis effects of dune development are explicitly included. It is shown that differences between the new dynamic roughness model, and models where the roughness coefficient is calibrated, are most pronounced after the floodwaves.

Introduction
In the Netherlands, hydraulic models such as Sobek, are used to predict water levels. The main-channel roughness often acts as calibration coefficient in these models.
In the main-channel of rivers, dunes form on the sand-bed, especially during floods. Observations show a hysteresis effect between discharge and dune height (Fig. 1).

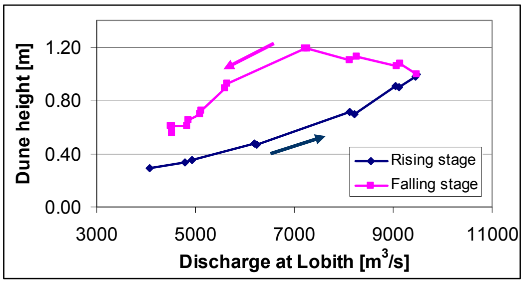

Figure 1: Hysteresis effect in dune height in the Upper Rhine during a flood (Wilbers, 2004)

In this paper, we present a model to predict water levels, which includes the hysteresis effect caused by dune development. This might result in better water level predictions over the entire range of floodwaves (rising stage, falling stage, and top/design discharge).

Roughness as garbage bin
The Chézy coefficient of the main-channel and floodplain are calibrated to match observed and computed water levels and discharge (distributions). All (model) errors end up in the roughness coefficient. In other words, the roughness coefficient acts as garbage bin of hydraulic models.
Figure 2 shows the calibration result for a relatively straight section of the Waal River, where the Chézy coefficients are a function of discharge, implying that hysteresis effects are not included in the model.

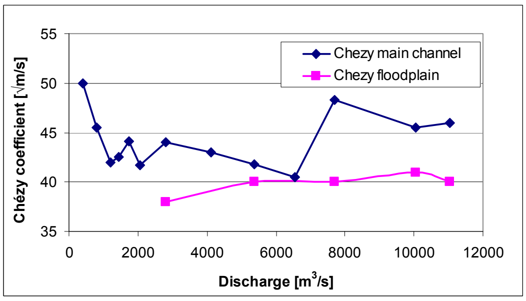

Figure 2: Calibrated Chézy coefficients of the main-channel and the floodplain as a function of discharge. (Waal rkm 885.23-900.88) (data from Udo et al, 2007).

Dynamic roughness model
We have developed a physics-based model to predict temporal dune evolution (Paarlberg et al., submitted). This model is now linked with Sobek to form the DrDude-model (**D**ynamic **r**oughness of **Du**ne **de**velopment). Figure 3 presents an overview of the model. Computed dune dimensions are translated into a roughness coefficient which is used in Sobek to compute the effects on water levels.

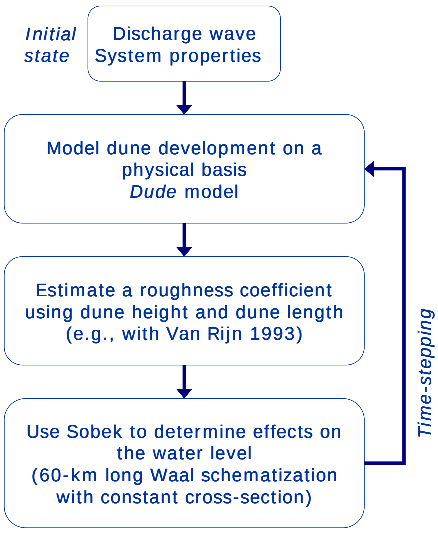

Figure 3: DrDude-model overview.

As Sobek model we use a simple 60-km long, straight channel with constant cross-section and channel slope, which is representative for the Waal River. In terms of Nikuradse roughness height, the roughness consists of:

$$k_{total} = k_{grain} + c k_{dunes} + k_{error}$$

where k_{grain} is grain roughness height, k_{dunes} is dune roughness height, and k_{error} represents the roughness height caused by (model) errors. k_{grain} is neglected with respect to k_{dunes}. The term 'k_{error}' is not known, and is therefore set to zero. The coefficient c = 0.35 is applied since dunes do not cover the complete river width and Van Rijn's relation was mainly based on flume tests.

Results

The DrDude model is used to simulate dune development and effects on water levels for two subsequent discharge waves (Fig. 4). There are periods of 1 week constant low discharge in between to initialize dune formation. At the start of the simulation the initial dune height is 5% of the average water depth in the main-channel. For the second discharge wave, the dune height is in equilibrium with flow conditions, at the start of the wave. Figure 5 shows a clear hysteresis in dune height, for both waves. The hysteresis in dune height also leads to hysteresis in roughness height since this is linked to dune dimensions (Van Rijn, 1993).
The effects on water levels are compared with the originally calibrated model in Figure 6. Differences occur especially after the floods, mainly because hydraulic models are calibrated on peak discharges.

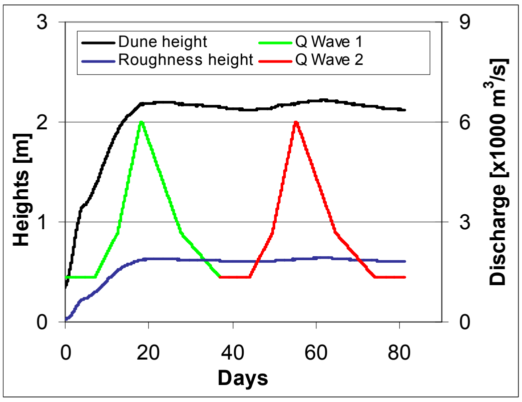

Figure 4: Two subsequent discharge waves with a sharp peak and periods of 1 week constant low discharge in between. Dune height and roughness height development over time are also shown.

Conclusions & Future work

Dune development, hysteresis in dune height and effects on water levels are successfully modelled with the DrDude-model. At the discharge peaks, there is not much difference in water levels, but in the falling and rising stage, there are some difference, especially after the waves. This modelling approach improves our physical understanding of the roughness coefficient of hydraulic models.

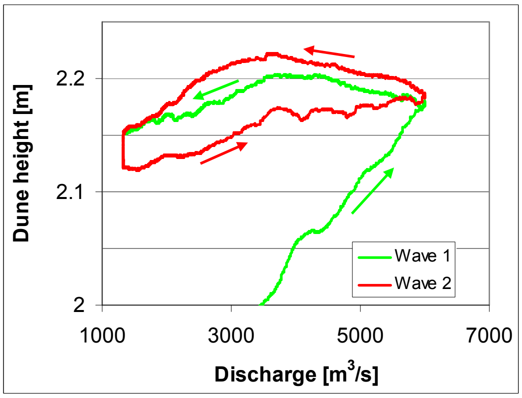

Figure 5: Hysteresis in dune height, for the two subsequent discharge waves. The arrows give the direction of development.

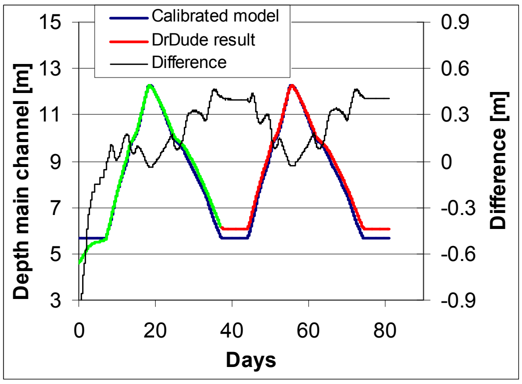

Figure 6: Comparison of DrDude model and the originally calibrated Sobek model.

Future work should aim on further increasing the knowlegde on elements in the garbage bin. Disentangling 'k_{error}' is necessary to find the next essential element in calibration. The model will be applied to other river sections (Upper Rhine) or other rivers (e.g., Meuse).

Acknowledgements

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Timescales and Information in early warning system design for Glacial Lake Outburst Floods

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Abstract
The risk for a Glacial Lake Outburst Flood can be defined and estimated for different stages of risk build-up. When making rational decisions, risk calculations depend on the decisions of local people in later stages. This makes bottom-up approaches essential for the planning and design of risk mitigating measures such as early warning systems.

Introduction
Glacial Lake Outburst Floods (GLOFs) are among the most devastating and unpredictable flood events in the world (Mool et al., 2001; Jianchu et al, 2006). Especially on a very local scale, their occurrence can have a major impact on the livelihoods of isolated mountain communities.
Glacial lakes are formed between the (often retreating) glacier and its end-moraine. Changes in the Himalayan climate over the last decades have led to an increase both in size and number of these moraine-dammed lakes. If the pressure on the moraine dam becomes too large, it can collapse by several failure mechanisms. In case of dam failure, a debris-laden flood wave travels hundreds of kilometers downstream. These flood waves can be several orders of magnitude larger than rainfall induced floods.

Risk based decision making for disaster mitigation

Engineering definition of risk
In engineering risk is usually defined as the statistical expectation of damage

$$risk = E(D(X)) = \int f_X(X)D(X)dX \qquad (1)$$

In which *D(X)* is the damage function of state vector *X* and f_X is the probability density function of the state vector. This means that risk is defined as the probability of an event multiplied by the consequence of an event integrated over the range of possible events. An example for quadratic damage function of deviation from optimal water level in a Dutch canal can be seen in Fig. 1. The surface below the lower graph is the risk. An automatic control system tries to minimize risk by finding optimal pumping actions that influence the future probability distribution of water levels in a beneficial way (Weijs et al., 2006; van Overloop et al., 2007).

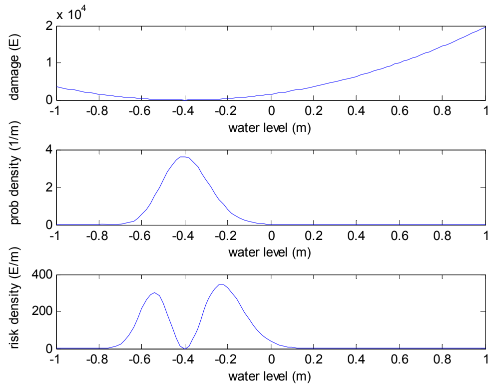

Figure 1. Example risk calculation in Dutch context. (Damage function, probability density function and the product of the two) Risk is the area under the lower graph.

Risk based decision making in uncontrollable systems
When trying to minimize risk posed by GLOFs, it is often impossible to influence the water flows, simply because they are too large to control (there are no large reservoirs present in the area). Therefore we can only influence the risk by influencing the damage function. We then do not take actions influencing the water system, but the system of interests connected to it (Fig. 2).

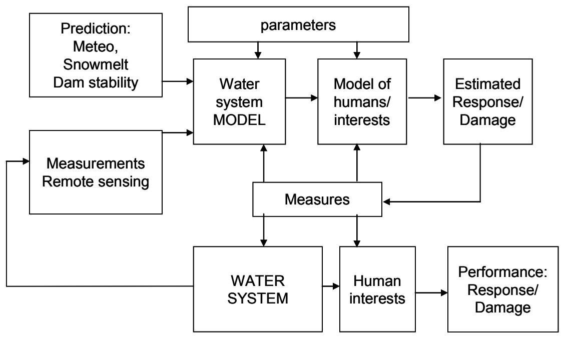

Figure 2. Model based decisions for water-human system

Examples of possible actions that could be taken on different timescales are relocating villages, evacuation of people, evacuation of cattle and storing food in safe places. All these measures cause certain discomfort or costs that have to be weighed against the resulting decrease in risk. To be able to make rational decisions both impact studies (e.g. Ives, 1986; Vuichard and Zimmerman, 1987) and probabilistic forecasts are necessary.

Timescales and Information for decision making

Stages of risk build-up

Glacial lake outbursts are sudden phenomena, but several stages can be considered in the process leading to failure of moraine dams and the time between failure and impact:

1. The existence of a potentially dangerous lake, which causes a background risk.
2. Growth in lake size and increased lake levels result in a temporarily increased risk.
3. Occurrence of the dam-failure, flood wave still travels
4. Impact of the flood-wave on human interests downstream.

For each stage both the probability and the potential damage need to be considered when selecting measures.

Necessary information for decisions

For each stage, new actual information is needed to estimate the actual risk to decide upon measures to be taken. Because of the different timescales, also the range of possible measures varies.

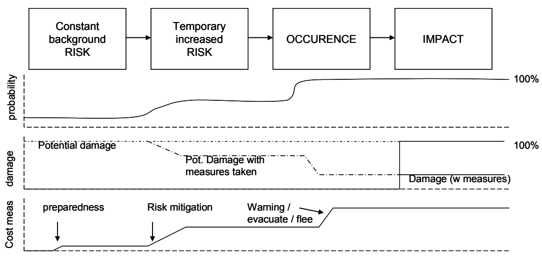

Figure 3. Risk build-up in the different stages of a GLOF. Increases in probability have to be compensated by actions decreasing potential damage.

For example, the lead time between the dam failure and the arrival of the flood wave in populated areas is in many cases in the order of minutes, leaving no other option than rapid evacuation. In the setup of an early warning system for glacial lake outburst floods, all stages of the build-up of risk need to be considered simultaneously (Fig. 3).

Early warning systems and mitigation

Monitoring networks are necessary for any prediction or warning system in this data-poor environment. Depending on the stage, information for early warning originates from remote sensing, fieldwork, water level sensors and needs to be gathered, processed and disseminated (Fig. 4). The end users of the warnings are mainly the people living in the flood-prone areas. The information that is needed in the warning depends on the options people have to influence their risk and how they perceive information. This should be the starting point of the warning system design.

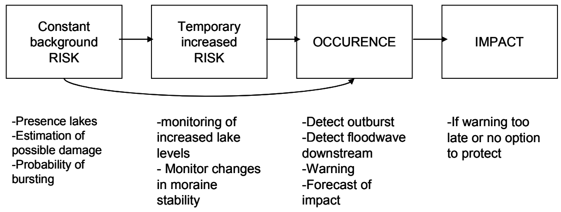

Figure 4. Types of monitoring in the different stages, necessary to estimate risk

Also information about the way local people traditionally anticipated risks and about traditional warning mechanisms is essential (Dekens, 2007).

Conclusions

Because the interconnection between actions and risk on different timescales, all stages in risk build-up need to be considered simultaneously. In this way the decisions in earlier stages depend on possible decisions in later stages. Because these are often taken by local people, based on their knowledge and available information, a bottom up approach is needed in design of early warning systems for hazards like Glacial Lake Outburst Floods.

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Effect of heterogeneous bed roughness on the conveyance capacity of floodplains

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Abstract
The hydraulic roughness of a floodplain determines the floodplain's conveyance and the associated flow structure. Especially in floodplains, the bed roughness is heterogeneous, which complicates establishing a roughness parameter representative for a grid cell in a numerical model. Specifically, the distribution of roughness elements within the grid cell may influence the effective drag exerted on the flow. Recent laboratory experiments (Jarquín, 2007), using a flume with a parallel smooth and a rough lane, showed that the friction factor for a heterogenic bed was about 80% higher than theoretical values, based on the individual friction factors. The present research elaborates on the work by Jarquín (2007), focusing on the characteristic length scales in which the flow is adapting to changes in bottom roughness. Preliminary results suggest a prominent role of secondary circulation above the smooth to rough transition. This secondary circulation can be explained by the turbulence energy budget.

Introduction
Bottom roughness is a key factor in modelling open channel flow. Estimates of the hydraulic bottom roughness can best be inferred from velocity profiles, turbulence and water level measurements, but hydrographic measurements in floodplains are sparse. Therefore an estimation of roughness parameters based on the bed constitution is often used. The bottom roughness in floodplains is in general very heterogeneous. The conveyance capacity could be calculated as a sum of the capacities for each roughness section, but this straightforward method neglects interaction between the sections. A recent study showed that the conveyance capacity of two parallel roughness sections is about 25% lower than the theoretical conveyance based on the individual roughness parameters (Jarquín, 2007). In other words, the effective friction factor is higher than theoretically expected based on the individual friction factors.
To fully understand the interaction between the sections, this study is focussing on the mixing layer in between parallel sections with respectively a rough and smooth bottom. One of the mechanisms of transverse momentum exchange in the mixing layer appears to be a secondary circulation. This circulation has been observed before (Studerus, 1982; Nezu & Nakagawa, 1993), but the quantitative importance and its length scales are poorly understood.

Experiment setup
The experiments are executed in a 2-meter wide horizontal flume at the Fluid Mechanics Laboratory of the TU Delft. The bottom consists of a hydraulically smooth section (wooden plates) and a rough section (stones with d_{50} = 7.6 mm); see figure 1. Velocity measurements are taken with an Acoustic Doppler Velocimeter (ADV) and Particle Tracking Velocimetry (PTV). Furthermore, a Large Eddy Simulation (LES) is used to compute similar experiments in detail.

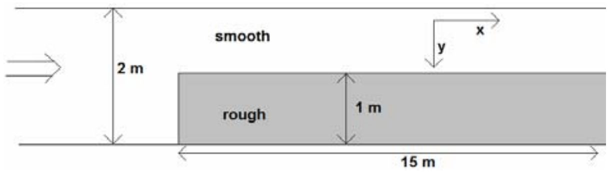

Figure 1: configuration of experimental flume

Secondary circulation
The velocities over a cross section, measured using an ADV, show a pronounced secondary circulation (figure 2). The circulation has a velocity magnitude of 1 to 2% of the streamwise velocity and its centre is located above the smooth bed. This secondary circulation can be explained by turbulence anisotropy (Nezu & Nakagawa, 1991). It also follows from the turbulence energy balance equation, which can be simplified to (using a boundary layer approximation and neglecting small terms; see Hinze, 1967):

$$\overline{u_y} \cdot \frac{\partial}{\partial y}\frac{\overline{\mathbf{u}'\cdot\mathbf{u}'}}{2} + \overline{u_z} \cdot \frac{\partial}{\partial z}\frac{\overline{\mathbf{u}'\cdot\mathbf{u}'}}{2} = -\overline{u_x'\cdot u_y'}\frac{\partial\overline{u_x}}{\partial y} - \overline{u_x'\cdot u_z'}\frac{\partial\overline{u_x}}{\partial z} - \varepsilon \quad (1)$$

in which $\mathbf{u}$ is the velocity vector, ε the turbulence dissipation and apostrophes denoting a deviation from the mean. At the rough side of the interface, turbulence production exceeds the dissipation; resulting in a positive value at the right hand side of equation 1.

Since it can be assumed that

$$\left|\frac{\partial}{\partial z}\frac{\overline{u'\cdot u'}}{2}\right| >> \left|\frac{\partial}{\partial y}\frac{\overline{u'\cdot u'}}{2}\right| \text{ and } \frac{\partial}{\partial z}\frac{\overline{u'\cdot u'}}{2} < 0 \text{, this}$$

implies w<0 above the rough bed and w>0 above the smooth bed. This leads to the secondary circulation as observed in figure 2. Measurements show that the momentum exchange caused by transverse advection (due to the secondary circulation) is of the same order of magnitude as the momentum exchange due to mixing layer vortices in the horizontal plane.

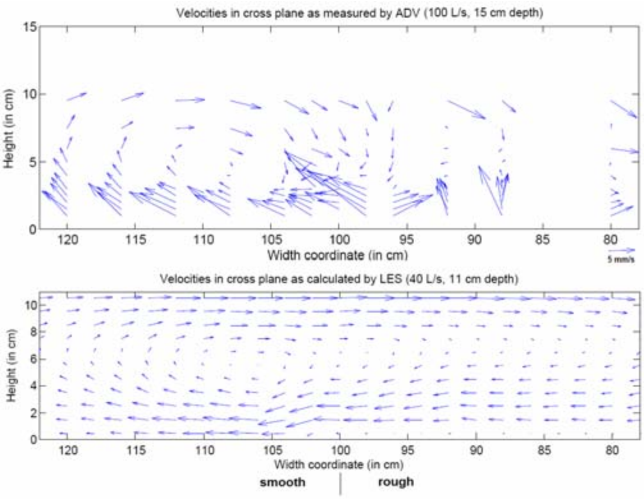

Figure 2: time-averaged velocities in a cross plane in a developed flow over a parallel smooth-rough bed

Effective roughness

The theoretical specific discharge is calculated by (Darcy-Weisbach):

$$Q_{theory} = A \cdot \sqrt{\frac{g \cdot R \cdot S}{2}} \cdot \left(\frac{1}{\sqrt{f_{smooth}}} + \frac{1}{\sqrt{f_{rough}}} \right) \qquad (2)$$

In which

Q_{theory} = theoretical discharge
A = area of total cross section
R = hydraulic radius
S = water level slope
f = friction factor

The actual equivalent friction factor can be calculated from the measured discharge:

$$f_{equivalent} = \frac{2 \cdot A^2 \cdot g \cdot R \cdot S}{Q_{measured}^{\;2}} \qquad (3)$$

Based on data of Jarquin (2007), the measured equivalent friction factor is almost twice the expected theoretical values (table 1); which results in a 25% reduction of the discharge.

Table 1: friction factors, theoretically (based on the individual friction factors (eq. 2)) and measured (eq. 3). Based on data from Jarquín (2007)

Q (L/s)	Depth (cm)	$f_{eq.\ theoretical}$	$f_{eq.\ measured}$
76	13.5	0.029	0.052
76	15.0	0.027	0.048
76	18.0	0.025	0.048
100	14.8	0.029	0.045
100	16.0	0.027	0.047
100	18.0	0.025	0.044

Development lengths

A LES shows that at short distances (20x depth) from the start of a parallel smooth-rough bed (as in figure 1), no secondary circulation occurs.
Future work is dedicated to the flow over a bed with alternately changing sections of smooth-rough (i.e. resulting in a checkerboard of smooth and rough bed sections). First LES results of such a configuration show even a higher friction factor (5% higher) than the parallel roughness configuration.

Conclusions

Flow over a bed with compound roughness has a clearly lower conveyance than based on individual roughness parameters. A secondary circulation occurs in the developed flow, which causes a momentum exchange in the same order as those due to vortices in the horizontal plane. The development length of this secondary circulation appears to be longer than 20 times the water depth.

Acknowledgments

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The effect of polder compartmentalisation on the inundation of the "Land van Maas en Waal", the Netherlands

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Abstract
This contribution addresses the consequences of a flood in the Land van Maas en Waal. To assess the effect of compartmentalisation on the spatial distribution of risk within the polder, 28 flood scenarios were simulated using a 2D flood propagation model. Spatial Multi-Criteria Evaluation is used to include the needs of the end-users of the risk map as well as their perception of which parameters contribute to risk. It is concluded that flood simulations in combination with multi-parameter risk assessment are useful for decision-makers, but also for rescue workers who may use the results in preparation for the next flood catastrophe.

Introduction
The present compartmentalization layout within the river polders in the Dutch Rhine-Meuse delta is the result of abandonment and partial removal of secondary dikes and of the construction of modern infrastructure embankments (Alkema and Middelkoop, 2005). These structures will guide the flow of water in case the polder inundates. A systematic set of 28 flood scenarios was simulated and it was concluded that neither removal nor total restoration of compartmentalizing elements resulted in a reduction of the total flood damage (Alkema, 2007). Only a strategic compartment plan to delay the flow of water towards vulnerable areas may reduce the risk.

Multi-parameter assessment
It was also concluded (Alkema 2007) that risk assessment techniques that use only inundation depth as input, do not give a good spatial representation of the flood risk in such a polder area. First of all, because the compartment dikes are of limited height, they are quickly overtopped and have thus little effect on the maximum water depths in the inundated polder. This limits the use of water depth as proxy to assess the spatial distribution of risk. A second shortcoming is that the maximum water depth is only one of many flood-related parameters that contribute to the impact of the flood water. Other risk-defining parameters are f.i. duration, flow velocity, warning time, etc. The severity of the impact is the result of a combination of factors: high water depths, high flow velocities, long duration, short warning time, etc. And a third consideration that is lacking in current risk assessment is the perception of risk. This perception depends large on the concerns regarding floods of those affected and those that will have to respond to such a calamity. The concerns of a farmer will be different than those of someone living in a village; rescue workers require other information than damage assessment teams; etc. A risk assessment made for one purpose, may very well be useless for another.

Spatial Multi-Criteria Evaluation
The problem of flood risk being a function of multiple parameters and perception can be solved using Spatial Multi-Criteria Evaluation (SMCE). SMCE is a GIS-based procedure to structure complex spatial problems and to support balanced decision-making while considering different parameters (Malczewski, 1999). It forces the users (decision-makers) to define their objectives and to state their information requirements. Once the objectives are defined, SMCE guides the (group of) evaluators through a process to combine and transform geographical data (input) into a decision (output). This process includes, apart from geographical data, also the decision maker's preferences and the manipulation of the data according to specified decision rules. The result is a spatial aggregation of multi-dimensional information into a single parameter output map: the decision.

For the Land van Maas en Waal study, the 28 flood scenarios are based on 7 dike breach locations and 4 different topographical lay-outs inside the polder. The recurrence probability (annual probability of occurrence) of the simulated event coincides with the design norm of the dikes, which for the Land van Maas en Waal is 1:1250 (Randvoorwaardenboek, 2001). For each scenario, 7 flood parameter maps are computed: 1) maximum water depth, 2) maximum flow velocity, 3) maximum impulse, 4) maximum rate of water level rise, 5) flood propagation time, 6) flood duration, and 7) sedimentation and scouring. These flood parameters maps show the complex spatial-dynamic behaviour of a flood event and immediately demonstrate the complexity of defining risk in the polder area: what is worse, short warning times or higher maximum water depths?

In practice it will turn out that different user groups will assign different priorities to different flood parameters and will apply different aggregation procedures. Thus for the same event, different flood risk maps may coexist. The results can be interpreted as priority areas for a predefined goal or objectives. For example, if the goal is to define priority areas for evacuation (which people have to be evacuated first) the map presented in Figure 1 can be used. If the objective is to identify areas where the largest damage will occur, the map in Figure 2 can be used.

Conclusion

The topography of the polder strongly affects the propagation of the flood water and therefore plays an important role in the spatial distribution of risk. Floods are complex spatial-dynamic events and traditional methods that use only water depth as risk-proxy tend to simplify the risk distribution in the area. Other flood-parameters should be included as well. In this study is shown that: a) Spatial Multi-Criteria Evaluation can be used to derive multi-parameter flood risk maps, and b) the definition of risk depends on the perception and concerns of the end-users of the map. For the same flood event, different perceptions of the risk may coexist which will result in different flood risk maps. Acknowledgement of these differences will result in more applicable information for the stakeholders and thus facilitate the incorporation of flood considerations in the decision-making process.

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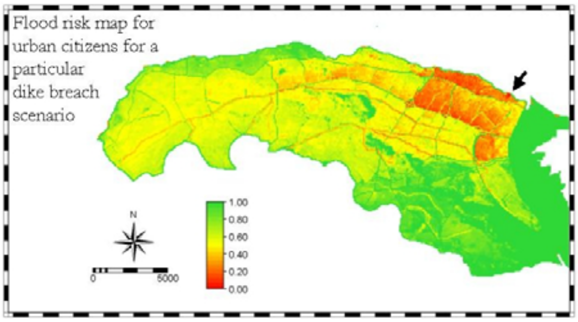

Figure 1. Risk map for evacuation purposes (evacuation priority) in case the dike breaches at the location indicated by the arrow.

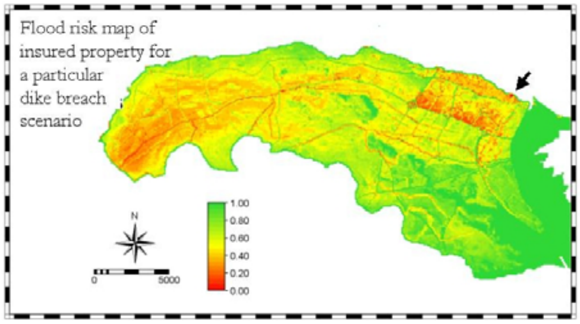

Figure 2. Risk map for damage estimation (for e.g. insurance purposes).

Palaeogeography and deltaic flood safety: extreme floods of the lower Rhine in the last 5000 years

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Abstract
In the Netherlands, improved knowledge on frequency-magnitude relations of extreme discharge/flood events is in great demand. It raises the need for extending the period of observations beyond the monitored last 200 years. This extension can be found in the sedimentary archive of the Rhine-Meuse delta. To aid frequency-magnitude statistics in the 1/50-1/2000 recurrence range and to pin-point one “design flood” in the recent geological history, we advocate targeted new research in the upstream part of the delta (Cohen & Lodder, 2007).

Introduction
In the Dutch delta, safety against flooding is mainly determined by the frequencies of (a) extreme discharges of the Rhine and (b) major storm surges on the North Sea (Fig. 1). Design standards for the primary flood defence structures are based on an annual failure probability of 1/1,250 to 1/10,000. The frequency-magnitude relationship for such extreme events, however, is not exactly known: It is present practice to use a statistical extrapolation of measured discharges in the last 100-200 years (Chbab & Van Noortwijk, 2002) to estimate the magnitude of events of 1/1250 yearly probability for extreme river discharges. For the Rhine this yields a discharge of 13,000–18,000 m^3/s (95% confidence); the current design discharge for the Rhine is 16,000 m^3/s (Fig. 2).

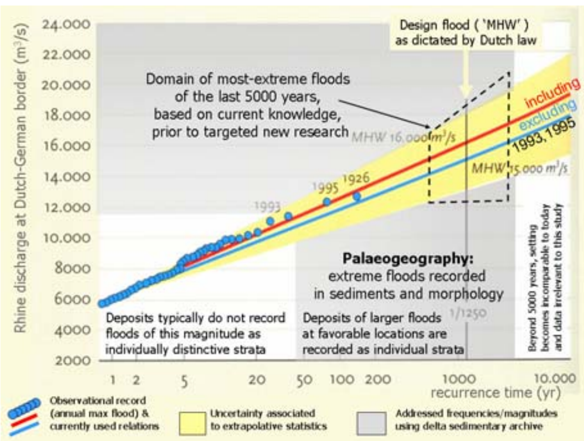

Figure 2. Uncertainty in discharge of the Rhine in the low frequency-high magnitude range (Cohen & Lodder, 2007).

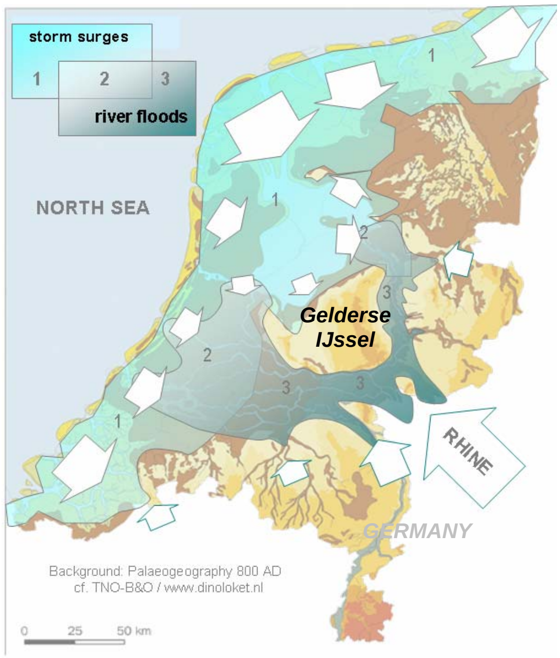

Figure 1. Sources of flooding in the Netherlands in the natural situation (Cohen & Lodder, 2007).

5000 years sedimentary flood history
The Dutch delta is the outcome of the waxing and waning, avulsion, bifurcation and abandonment of river channels as the result of natural flooding. The build-up of the subsurface and the shifting controls explaining the result are understood in great detail, especially for the last 5000 years (Berendsen and Stouthamer, 2001; Cohen, 2005; Gouw & Erkens, 2007).
These reconstructions have not yet addressed identification or analysis of specific extreme flood events. Nevertheless, the extremely detailed database (lithology, digital elevation, ages) with its complete coverage provide a unique starting point to target extreme flood recording at century to millennial time scale in the sedimentary archive.

Complementary methods
We formulated a double-headed approach (A1, A2) to establish a frequency-magnitude dataset for Rhine discharge over the last 5000 years. A1 yields the magnitude of one extreme flood; the complementary approach A2 assesses the frequency of such high-magnitude floods.

A1: Flooding and the Gelderse IJssel

An important role is attributed to the formation of the Gelderse IJssel river branch (Fig. 1). We relate the initiation-event of this channel (timed between 350-500 AD) to an extreme flood, unsurpassed ever after. The 'IJssel'-event offers a chance to pin-point a 'design-flood' in geological history. Furthermore, since this bifurcative branch diverts water away from the rest of the delta, Rhine peak discharges of given magnitude caused higher floods in the central delta before the IJssel came into existence than afterwards.

The IJssel-creating flood left widespread geomorphological and sedimentary traces. These have sufficiently preserved today to reconstruct water levels, water depths, gradients and dimensions of series of crevasse splays and –channels. Reconstruction of the first 'initiating' flooding provides a suitable case for numerical modelling: the discharge necessary to maintain the reconstructed state can be model-calculated (by inverse application of state-of-the-art models). This delivers a realistic bandwidth for the magnitude of Rhine discharge needed to create such large flooding, of a magnitude comparable to the concurrent design flood.

A2: Residual channel flood records

A sedimentary archive documenting the history of extreme peak-discharges lies enclosed in fills of residual channels, oxbow lakes and dike breach scours along active and former river branches. For the upstream part of the delta (20-km radius around the present delta apex at the Dutch-German border, Fig. 1) this archive can be used to establish frequency-magnitude estimates.

Individual fill sequences (2-4 meters thick) reflect sedimentation of semi-annually flooding nearby rivers, typically recording 500-1000 year periods until filling was complete. The age of individual fills is known accurate to ~250 years – and can be improved with further dating. In addition, the distance of these fills to bifurcating, avulsing and migrating coevally-active channels is fully known (Berendsen & Stouthamer, 2001).

For about 40 sites, the history of flooding is to be determined from thin layers of distinct sediment that settled following severe flooding, encased in sediments that accumulated during normal floods. Routine laboratory analysis (variations in grain size and organic matter content, radiocarbon and historical-palynological dating) of cores from these fills at high resolution yields a local flood record. The ensemble of local flood records collected over the full width of the Rhine delta covers the flooding history of the last 5000 year and would allow to list frequencies of peak floods for several (qualitative) magnitude classes.

Conclusion

Datasets and strategies are presented that can provide knowledge on Rhine floods of rare recurrence (1/50 – 1/2000 per yr). The presently available data base enables a focused data-collection strategy, to reconstruct the discharge distribution history over the lower Rhine branches at the changing bifurcate nodes. This will furthermore reveal the spatio-temporal occurrence of peak discharges in the past millennia (when did the largest floods occur and how large was the largest?), resulting in a reduction of the uncertainties in the estimates of occurrences of extreme floods. Thus, the sedimentary record of the Holocene Rhine-Meuse delta provides a source of information that promises to reduce the uncertainties of the estimates of magnitude/frequency relations of extreme floods (50 – 2000 yr recurrence times). It thereby forms a valuable extension of the existing estimates, derived from statistical extrapolation of the short observation records.

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New methods to quantify land subsidence due to peat compaction (Cumberland Marshes, Canada)

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Abstract
In lowland deltaic environments, land subsidence due to compaction of unconsolidated sediments, and especially peat, may lead to an increase in flooding risk as floodplains subside, damage to constructions and problems in groundwater management. Furthermore, (peat) compaction may influence the occurrence of avulsion, and hence play an important role in delta evolution. Avulsion is a natural process by which a part or the whole of a channel belt is abandoned in favour of a new course (Allen, 1965). To quantify effects of peat compaction on delta evolution, new methods are used during a field study in the Cumberland Marshes (Canada). The first method is mainly based on relations between the bulk density of compacted and uncompacted peat. The second focuses on thickness variations of a peat layer in combination with the thickness and type of overlying sediments (lithostratigraphy). To take undisturbed samples of fresh peat, a new coring device is developed. Both methods are successfully applied in the field and valuable field data has been collected, which is currently being analyzed.

Introduction
Compaction and oxidation of peat leads to land subsidence. This has important implications for groundwater management and may also lead to an increase in flooding risk and damage to buildings and roads. Furthermore, peat compaction may influence the occurrence of avulsion (Michaelsen et al., 2000; Rajchl and Uličný, 2005). Avulsion, the partial or full abandonment of a channel in favour of a new course, is the principal process in the development of deltaic and alluvial plains, because is controls the spatial distribution of fluvial sedimentation and determines the channel recurrence interval on the floodplain, and as a result, channel density and interconnectedness (Allen, 1965; Leeder, 1978). Relations between peat compaction, avulsion, and hence delta evolution are not understood however, mainly because of a lack of reliable field data. Therefore, field work has been carried out in the Cumberland Marshes (Canada, Fig. 1).

The landscape in this area is comparable to the western Netherlands, only without human interference. During the field study, new methods were used for quantifying the amount of land subsidence due to compaction, which are presented in the following sections.

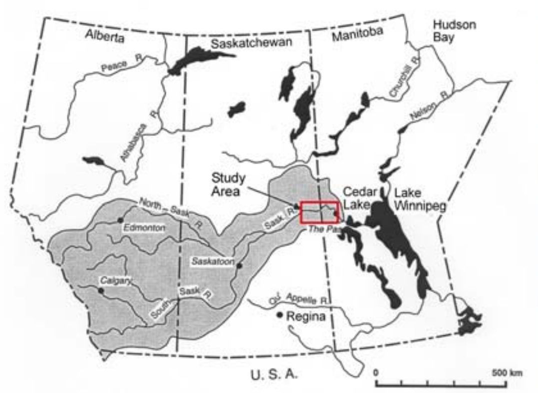

Figure 1. Location of the Cumberland Marshes, Canada (figure taken from Smith and Perez-Arlucea, 2004).

Methods
Bulk density measurements
The first method is based on relations between bulk densities of compacted and uncompacted peat. The original thickness of a compacted peat layer can be calculated by multiplying the thickness of this layer with the ratio between the compacted and uncompacted bulk density. Bulk densities of compacted peat at different depths are measured by taking 5cc (5x1x1 cm) samples at a 5 cm interval directly from a 30 mm wide gouge auger. Each 5cc sample is saturated with water to determine wet bulk density, dried at 105 ºC to determine dry bulk density, and heated at 550 ºC to determine Loss On Ignition (LOI; organic matter content). Due to the heterogeneity and loose structure of fresh peat it is difficult to determine the characteristics of uncompacted peat by field sampling. Existing coring devices used for peat sampling often disturb the sample and/or take too small samples to take into account the heterogeneity of peat. Therefore, a new coring device is developed (Fig. 2). The cylindrical shaped corer uses sharp cutting blades to cut through twigs and other plant remains, while leaving the internal structure intact. To minimize disturbance, only the middle section of the 25 cm long sample (ø 106 mm) is used for density and LOI measurements.

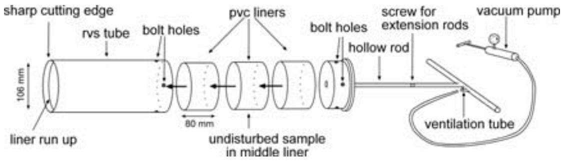

Figure 2. Schematic representation of the coring device used to take undisturbed peat samples.

Lithostratigraphy

The second method focuses on thickness (and bulk density) variations of a peat layer in relation with the thickness and type of overlying fluvial sediments. The highest amount of compaction is expected at locations where the overlying sediment layer is relatively thick and consists of relatively sandy material. Such conditions occur for example underneath levees. A low amount of peat compaction is expected further away from the river channel in the floodplains, where the overlying sediment layer is thinner (or absent) and often consists of (organic) clay deposits. The amount of subsidence due to compaction can be calculated by assuming the base of the levee was initially horizontal in cross-section (Fig. 3).

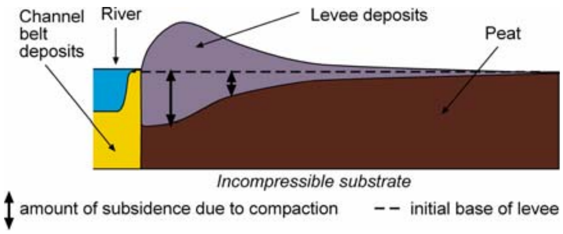

Figure 3. Calculating the amount of subsidence due to compaction based on lithostratigraphy.

For this method, detailed cross-sections running from a levee to the floodplain (perpendicular to flow direction) are needed, which are constructed based on coring data. Corings are taken using a gouge auger, using a coring distance depending on surface relief (mostly within a range of 2 to 10 m). Each coring is logged at a 10 cm interval for amongst others texture, colour, plant remains, oxidation/reduction and other specific characteristics such as the occurrence of shell fragments.

Results

Data gathered during this field study is currently being interpreted; here only some first results and ideas are given.
The new coring device for taking undisturbed peat samples was successfully used in the field. First analyses of the field data show that dry bulk density values (the amount of compaction) depend on the LOI (negative relation), the type of peat, burial depth and thickness and type of overlying sediments.

Six detailed cross-sections were made during the field study. It is seen that peat layers become thinner at places were it underlies a relatively thick (and sandy) sediment layer, for example underneath levees (Fig. 4). By dating the peat layer at different depths using ^{14}C dating techniques, time lines can eventually be drawn in such cross sections.

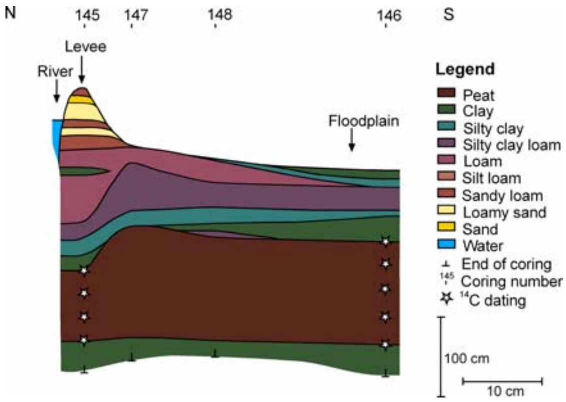

Figure 4. Detailed cross section based on coring data, running from a levee to the floodplain.

Conclusion

Effects of peat compaction on delta evolution are not known yet, mainly because there is a lack of reliable field data, and of a good method to collect such data. Therefore, an extensive fieldwork has been carried out in a marginally human-influenced natural river system. First analyses of the collected field data show that the amount of peat compaction depends on peat type, organic matter content, burial depth and type of overlying sediments. Detailed lithostratigraphic cross-sections show that peat layers are thinner underneath levees, which would suggest that peat compaction initially fixes river channels. This is still under investigation however.

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Early Holocene drowning of the Rhine river mouth

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Introduction

Worldwide, humanity has faced sea-level rise (SLR) for more than 20000 years now. In the western Netherlands (Rotterdam area) the direct impact started only 10000 BP (before present), when groundwater levels started to rise rapidly and the landscape changed from a river valley to an estuary. Today, we face an increase in sea-level rise and river mouths start to drown on a global scale. These areas are densely populated and it is important to understand how rivers react to sea-level rise and how coastal and fluvial processes interact under rapid drowning.
At depths of 12-18 m below the surface of Rotterdam (Fig 1.) lies a very well preserved sediment body dating from a rapid drowning period 8000-10000 BP (early Holocene). Because of a huge amount of corings, dates and seismic data, it is possible to reconstruct this drowning. Here, we present the latest results regarding sea-level rise and facies distribution in the study area.

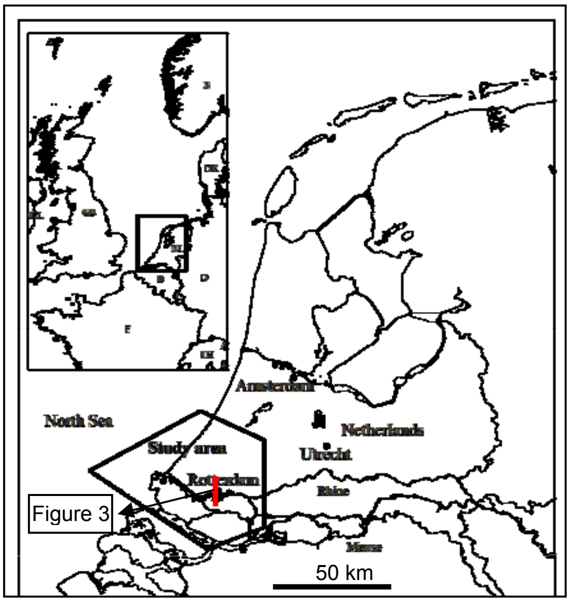

Figure 1. Location of the study area.

Relative SLR in the Early Holocene

In the Netherlands, land-surface subsidence (tectonics, glacio-isostatic movements) adds up to the global sea-level rise signal. Pioneering studies on SLR in the Netherlands have been carried out by Jelgersma (e.g. 1961) and Van de Plassche (1982), resulting in a very well constrained sea-level curve for the last 7500 years. During this study we collected new sea-level indicator points by dating peat-layers and were able to extend the curve back in time from 7500 to 10000 BP (Fig 2.).

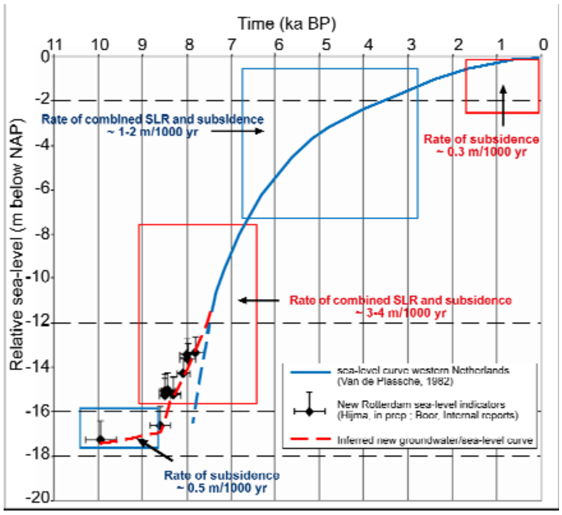

Figure 2. New extended groundwater/sea-level rise curve for the Rotterdam area. (Hijma, in prep.). Sea-level in the western Netherlands has always been rising because of continuous subsidence. Between 8500 and ~3000 years ago this rise was enhanced by a global sea-level rise signal.

The new data show that SLR was less steep in the period 8000-9000 BP then earlier was assumed by extrapolating the Van de Plassche-curve. The Pleistocene surface around Rotterdam lies at -17/-18 m below NAP. At this depth (9000-10000 BP) the curve flattens. It reflects rising ground-water levels not yet influenced by SLR.
Ongoing work will further increase resolution and will validate the current curve. Additional new samples show an earlier start of SLR recording to the west (Maasvlakte), compared to the data for Rotterdam centre, and a lagged start upstream of Rotterdam.

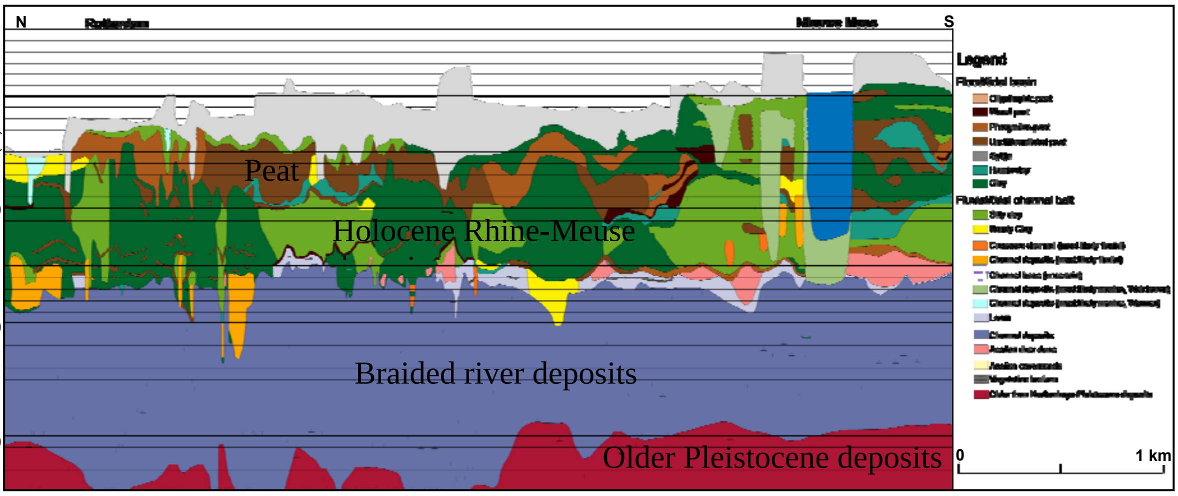

Figure 3. Part of a cross-section around the centre of Rotterdam (see also Fig.1) showing the highly variable facies distribution.

Facies distribution: cross-section

SLR and the change from river valley to estuary resulted in a complex and highly variable facies distribution. Therefore we constructed three long north-south cross-sections across the entire delta, in order to describe this distribution.

Figure 3 shows a small part of one of the cross-sections. The substrate consists of coarse fluvial deposits, mainly laid down by braided rivers. At the transition to the Holocene rivers incised deeply. During floods loam was deposited along these rivers. In dryer periods or periods of less sedimentation, small dunes could form along the edges of the rivers.

Due to SLR, floods increased and circa 8500 BP the channels were lifted out of their valleys and started to aggrade. A small tidal signal was already present. The constant increase of this signal resulted in a distinct layered sedimentation pattern. Still, the environment remained fresh due to the presence of the Rhine-Meuse rivers. The deltaic setting with many small channels resulted in a complex sedimentation pattern.

This situation remained fairly constant until circa 6500 BP. Then, an avulsion upstream caused the position of the outlet of the Rhine to move to the Leiden area (Berendsen and Stouthamer, 2001). The Rotterdam area changed into a backswamp and large scale peat formation started. Just north and south of Rotterdam marine influences were dominant until 5500 BP when the coastline was closed off by barriers (Beets and Van der Spek, 2000).

Peat formation continued until the Roman Period. Then the Rhine changed its course again to the Rotterdam area. Along the rivers clay deposits covered the peat. Especially during the Middle Ages, marine ingressions became more frequent and most of the peat was covered with a thin clay layer.

Ongoing work

Upcoming research on pollen and diatoms, together with several cross-sections, palaeogeographic maps, seismic data and new ^{14}C and OSL-dates will allow us to reconstruct the development of the Early Holocene Rhine-Meuse delta. This will lead to a better understanding of the linked coastal-fluvial developments and the processes involved. Final results will be published at the end of 2009.

Acknowledgements

Ton Guiran, Jurrien Moree and Ruben Lelivelt (BOOR, Rotterdam) are thanked for their cooperation and sharing of ^{14}C-dates.

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The impact of land-use changes on flood risk (water quantity) and sediment delivery (water quality) in the Nysa Szalona catchment, SW Poland.

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Introduction

Large-scale flooding in Eastern Europe (Lahmer, 2003; De Roo et al., 2003) forms dramatic constraints for the future economic development of the region. Apart from the excess of water, the hinterland also delivers large quantities of sediment, which accumulates in downstream reservoirs or forms problems in the fairway. To understand the processes of water and sediment generation in the headwaters of the major waterways it is important to look at these processes on a scale that is large enough to be representative of the processes involved and small enough to be homogeneous and thus allow unambiguous results: the meso-scale (50-400 km^2). However, the processes in these meso-scale catchments regarding the generation of sediment and water have, so far, not received much scientific attention (Lach and Wyzga, 2002; Saavedra, 2005; Keesstra, 2007).

In south-eastern Poland the Nysa Szalona catchment (350 km^2), was selected to conduct an investigation involving the interaction between land use and sediment and water delivery. The determining factors influencing the sediment and water delivery will be assessed.

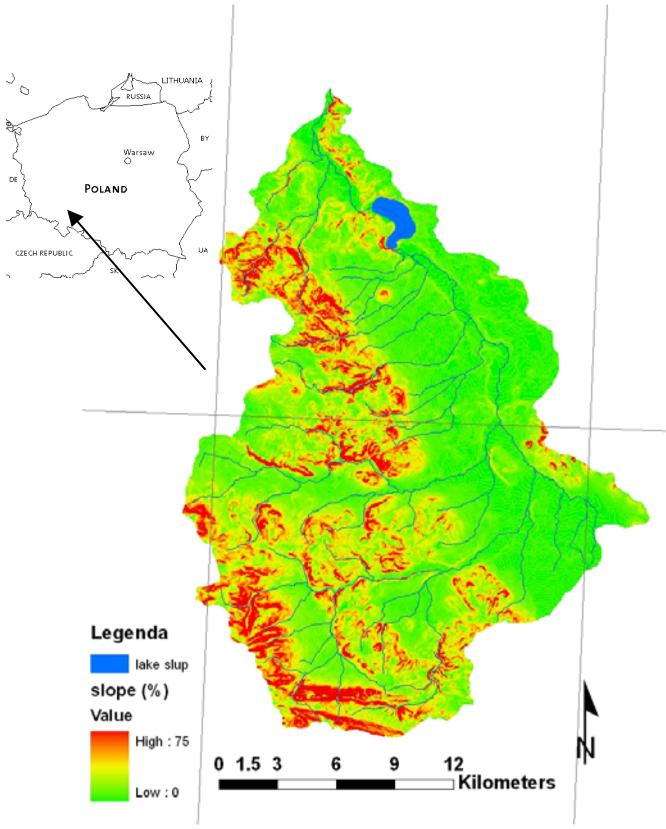

Figure 1: Slope map of the Nysa Szalona catchment in SW Poland (51° 00'N, 16° 05'E).

Aims

The general aim of the project is to explore the possibilities of land-use change and nature conservation in meso-scale catchments to reduce water and sediment delivery to the main river course. A thorough geomorphologic and ecological survey of the riverine habitat will be the basis of these scenarios. To test these scenarios an ArcGIS-based sediment delivery model with a strong hydrological and a snowmelt component is required. The available sediment delivery models are either not suitable for meso-scale catchments or only incorporate a selection of the active processes. Therefore, a model will be compiled from existing models for hillslope erosion, sediment transport and discharge routing. Because flooding events in the main river channels usually occur in spring when snowmelt is a significant factor in the water balance, the effect of snowmelt on sediment and water delivery will be incorporated.

Methods

Collection of model input data

The model requires input data, which are provided, partly by the Polish institutes, as well as through fieldwork campaigns. The data collection comprises of (i) soil/geological data; (ii) vegetation data (land use, current and historical); (iii) geomorphological data; (iv) hydrological data (current and historical): discharge, precipitation and snow cover; (v) digital elevation model; (vi) sediment load of Nysa Szalona (current and historical).

Field survey

During several field campaigns additional data needed for the model input (e.g. soil parameters, land use) will be collected. A general inventory of the sediment delivery history of the catchment will be made with an acoustic sonar survey of the downstream reservoir. The rivers morphological evolution will be mapped and linked to the sedimentation record in the downstream reservoir and to the historical discharge record. The historical hydrological record, the river morphology and sedimentation rates in the downstream reservoir will provide the necessary input for the model calibration and validation.

Furthermore, the riverine habitat in the meso-scale catchment will be ecologically mapped to collect data on the present situation. Both geomorphological and ecological characteristics will be used to develop scenarios for future nature restoration that will be beneficial for biodiversity as well as for sediment and water retardation.

Model development

Existing models usually incorporate only a selection of the active processes; the model scale is either a hillslope or a macro-scale catchment. Moreover, they only focus on sediment delivery or the water balance of a catchment. The available meso-scale GIS-based models have no or very little hydrological components and are usually empirically calibrated and not physically based. Consequently, the models are scale-dependent in terms of pixel-size, which will largely be excluded by introducing a strong hydrological component.

The new model will be compiled from existing models for the calculation of hillslope erosion, sediment transport and discharge routing within the model. Also the component of snowmelt will be incorporated in the model.

Land-use scenarios

Land use scenarios based on studies done in the Netherlands such as ‘room for the river’ (developed in the Netherlands) and ‘living river’ methodology (WWF) will be developed to enhance nature restoration around river, biodiversity enhancement. Moreover, these scenarios aim to retard sediment and water on their way downstream.

The effectiveness of land-use changes and nature conservation scenarios for the retardation of sediment and water in the meso-scale catchments will be tested with the newly developed model. The results will be evaluated on

(i) sediment retardation;
(ii) flood retention;
(iii) farmer needs and
(iv) nature development around the river (channel and riparian zone).

The results of this project are expected in 2 to 3 years.

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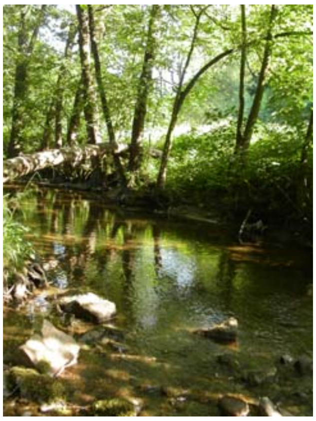

Two very differently managed tributaries of the Nysa Szalona. One totally regulated, the other naturally following its course. Part of this project is to see how these differences influence the discharge of sediment and water.

Tokyo and Dhaka: their battle against floods

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Abstract
People have always been attracted towards rivers. On the other hand, rivers can also cause floods, giving much flood damage. In Asia, two cities have to endure the constant threat of flood: Tokyo and Dhaka. Both cities use similar flood protection structures, such as floodwalls and embankments. There are also differences in flood control. Aesthetics and an appealing waterfront are in Bangladesh of less importance than in the more developed Japan.

Introduction
Water is of vital importance. Water feeds the rivers, supports agriculture and provides drinking water. Furthermore, rivers attract people because of their accessibility. Already in Ancient Times, world populations were drawn towards rivers. Water however, is not always friendly towards mankind. Its force can also destroy infrastructure, urban structures and can even lead to loss of human life. Floods are one of the many disasters which happen throughout the world each year.

Figure 1. Bangladesh and Japan are both Asian countries.

This paper focuses on the deltaic cities Dhaka, located in Bangladesh, and Tokyo, located in Japan, in Asia (Figure 1). The question is how these cities handle this threat. Are there similarities between the approaches of these cities or do they follow a different course?

City characteristics
Dhaka
Dhaka is the main capital of Bangladesh and is located in the central region of the flat deltaic plain of the transboundary rivers Ganges, Brahmaputra and Meghna. The city is surrounded by the Buriganga river at the south, the Turag river at the west, the Tongi Khal at the north and the Balu river at the east (Figure 2). The climate is classified as a humid tropical climate with a monsoon season. Bangladesh is highly vulnerable for flooding. For instance, the 2004 monsoon season affected about 36 million people of which nearly 800 people were killed (Beck 2005). Bangladesh is a country with a lot of agriculture which is strongly influenced by the flood behaviour of the rivers. Bangladesh's crop yield per hectare is one of the lowest in the world, despite the fertile soil caused by river floods (Younus, Bedford et al. 2005). Dhaka counts a population of approximately 6.7 million inhabitants at this moment and is still growing. Most of Dhaka West is already urbanised whereas Dhaka East, on the floodplains of the Balu river, is mainly a rural area. However, urban growth on this floodplain is becoming very dominant.

Figure 2: Buriganga riverfront of Dhaka

Figure 3: Sumida riverfront in Tokyo

Tokyo
Tokyo is the main capital of Japan and is located at the mouth of three large rivers: the Sumida river, the Ara river and the Edo river (Figure 3). Additionally many urban rivers flow in the Tokyo Metropolitan. Japan is situated in the East monsoon region with a warm and humid climate (Yoshimura, Omura et al. 2005). The country has twice as much precipitation as the world average (Infrastructure Development Institute-Japan and Japan River Association -). Furthermore it is affected by approximately 30 typhoons a year of which three typhoons hit the country directly. The country also has to endure many earthquakes. They do not only cause massive destruction but can also lead to dike breaches; followed by flooding. The city of

Tokyo is a city with a population of approximately 12.6 inhabitants and it has a large amount of assets, economic value and a highly developed network of infrastructure.

Flood management

Dhaka

Most fluvial floods in Dhaka are caused by overflow of the surrounding rivers during the monsoon season. This was for instance the case with the flood of 1988. Most structures were constructed or improved after this disastrous flood (Chowdhury, Rahman et al. 1998). Dhaka West, the urbanized part of the city, became encircled by embankments, flood walls and raised roads (Figure 4). This however had also consequences for urban water and led to problems with runoff control. Furthermore, agriculture within the embankments need annual flooding to grow (Chowdhury 2003). These side-effect have put the protection of Dhaka East on hold. Despite the rapid urbanisation in this part, the most common activity is still agriculture. The construction of embankments will have a serious effect on the harvest rate.

Figure 4: Embankments with flood walls in Dhaka

Figure 5: Flood walls in Tokyo

Tokyo

Tokyo is mainly protected with both flood walls and embankments (Figure 5). These floodwalls are mostly used at the urban rivers giving a concrete appearance. Hence, at the Sumida river a promenade has been constructed creating an appealing waterfront. The Ara river is partly diverted via a flood way which reduces flood discharges in the main river. This floodway was constructed after the huge flood of 1910. Another flood structure is the super levee which was introduced in the 1980s. This embankment has a broad width on which urbanisation is possible. It is resistant to earthquakes, overflow and seepage. In Tokyo, super levees have already been implemented along the Ara river and the Sumida river.

Comparison of the two cities

Both cities use similar flood protection structures, such as floodwalls and embankments. These flood structures are universal. Flood ways are however only found around Tokyo. Dhaka is surrounded with transboundary rivers which produce such an amount of discharge that only large river works might help. There is also a difference in the development of both countries. Bangladesh is one of the developing countries in Asia whereas Japan is one of the most developed countries. Flood defences in Tokyo, especially since the last decades, do not only have to be effective but also have to contribute to the value of the waterfronts. This is for instance the case with the super levee. In Dhaka, the riverfront is still mainly used for practical activities, such as offload and washing.

Conclusions

Both cities are protected against floods. The type of structure depends on the available sources, the physical constraints and the rate of urgency. Remarkable is that similar measures are found in both countries despite the economical differences. Exchange of knowledge remains important. It can induce innovative solutions which can lead to better protected cities.

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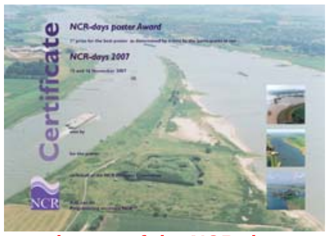

winners of the NCR-days poster Award 2007

Numerical and empirical study of annual flood dynamics in the Volga-Akhtuba floodplain

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Introduction

The objective of the NWO project is to quantitatively test the flood pulse concept, by analysing flood pulse dynamics in response to changes in river flow regime over different temporal and spatial scales, and relating these to the availability of floodplain habitats for recruitment and reproduction of riverine fish species, and thereby on fish population dynamics. To accomplish this objective a first step is to document and simulate the annual flooding patterns in the Volga-Akhtuba floodplain, using empirical analysis of observation records, field measurements and Remote Sensing data, combined with numerical modelling.

Study Area

The Volga-Akhtuba floodplain study area is situated east of Volgograd (Russia) and stretches about 30 kilometres from north to south and 100 kilometres from west to east. It is bordered by the Volga and Akhtuba Rivers. Due to spring snowmelt in the upstream Ural Mountains and the resulting discharge release at the hydropower dam near Volgograd, the floodplain is annually flooded. During the flood the main channels from the Akhtuba and Volga Rivers temporarily connect to a complex system of smaller channels and lakes within the floodplain, causing large areas to be flooded. The yearly flood is important for the unique biodiversity in this area.

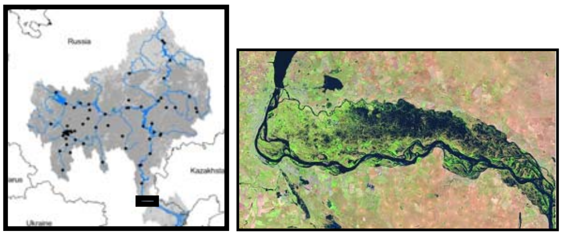

Figure 1. study area: a) Volga River basin with study area indicated by the black box, b) satellite image of study area (TM7 ETM+, P 171; R 26, 2003/05/25).

Field measurements

During summer low water 2006, channel profiles, bridge profiles, dikes and culverts were measured. This data is used as input for the numerical model. In spring 2006 and 2007 field measurements were carried out to measure flooding dynamics. Water levels and water temperatures were measured in lakes and important channels across the floodplain. In these channels flow velocity was measured as well to calculate discharge. In this way, the propagation of the flood through the floodplain can be quantified.

Figure 2. field measurements: a) levelling used for channel profiles, b) Ottmill used for measuring flow velocity.

The Volga discharge released from the dam upstream of the study area during spring 2007 flood is shown in figure 3.

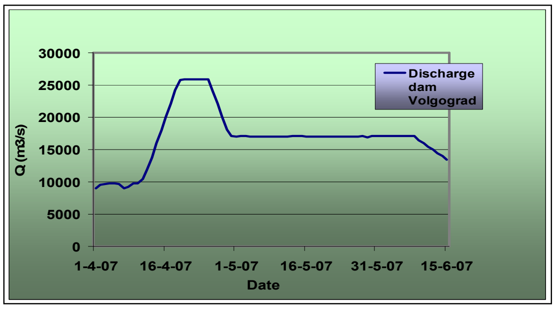

Figure 3. Spring 2007 discharge at the Volgograd dam.

The water levels (figure 4) and discharges (figure 5) measured in floodplain channels and in the Akhtuba River are increased during this period. These however, show a remarkable delay in timing, and varying peak height, depending on the location in the floodplain. Particularly the discharge curves in the central part of the floodplain reflect the slow depletion of the inundation after the peak flow.

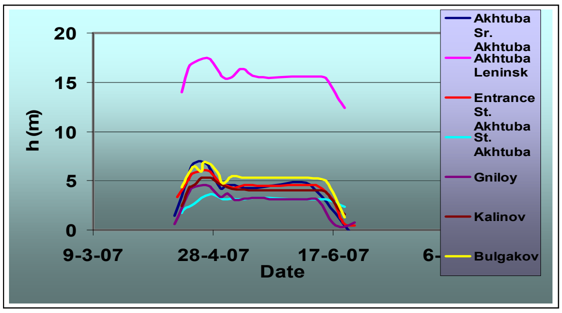

Figure 4. Water levels of spring 2007 flood at several locations in the floodplain.

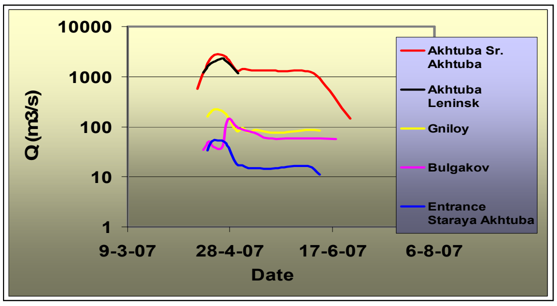

Figure 5. Discharge of spring 2007 flood at several locations in the floodplain.

Remote sensing

Satellite images complete the results by showing the complete 2D patterns of inundation at various stages of the flood. This provides information about the connectivity of the channels and lakes, mutually and to the main river, during the flood period. Time series of MODIS and Landsat TM satellite images from spring 2007 (figure 6) are used to estimate volumes of water in the floodplain in time to make a link with the field observations.

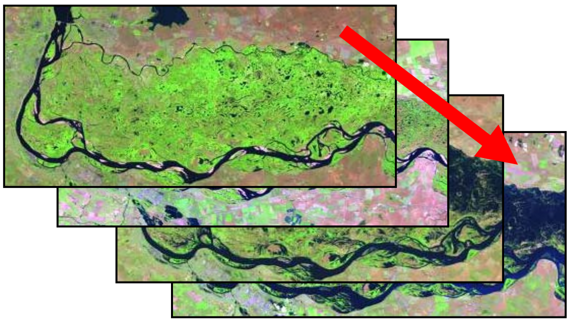

Figure 6. Time series of satellite images before and during the flood.

Numerical modelling

To simulate flood dynamics, a numerical hydrodynamic model is constructed using the 1D/2D module of the SOBEK Rural software package. Channels are represented as 1D elements, while the floodplain area as well as the Volga River well fits a 2D raster-based representation (figure 7). The model requires several input parameters, such as a digital elevation model (DEM), a roughness map for both the floodplain and in the channels, and locations of small embankments and channels. Also, cross sections based on field measurements, carried out during summer 2006, were added to the 1D channels.

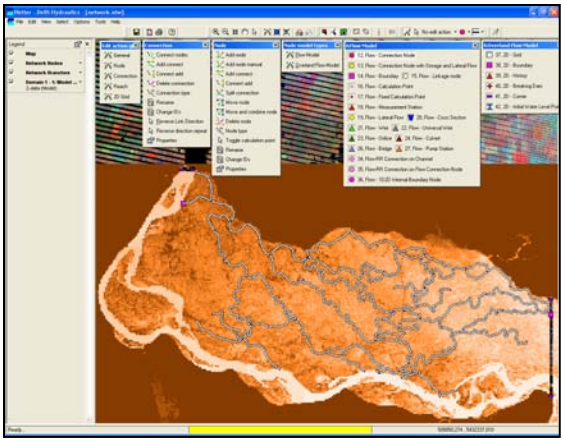

Figure 7. The SOBEK modelling interface. The DEM on the background represents the floodplain modelled in 2D, with 1D channels plotted on top.

The model calculates the 2D flow pattern (water level, depth, flow velocity and direction) over the floodplain, depending on the upstream river discharge. The model output thus represents a time series of flood extent and water depth for every model pixel. In figure 8 the model output of one time step is shown.

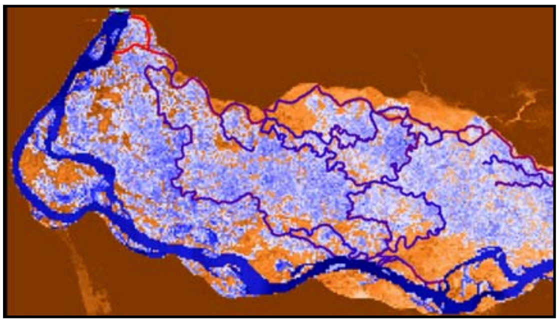

Figure 8. Model output: water level during peak flood. Dark blue represents the deepest water.

The sensitivity of this model is tested by changing the input parameters, such as evaporation, roughness values, and the used roughness parameter. The flood peak of 2006 is used to determine the models capability to simulate low flood peaks.

Future perspectives

With the empirical study and numerical model, flooding patterns will be distinguished. The flooded area, connectivity and flood duration will be examined in detail to describe the changing flooding patterns during a flood.

Remotely sensed soil moisture as early-warning for soil water and hydrological drought in the Rhine basin

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Abstract
Adequate drought warning systems are essential in drought risk management. A drought develops from a meteorological drought into a soil water and hydrological drought. Soil water and hydrological droughts cause large socio-economic damage and are therefore important to forecast alongside of meteorological droughts. Currently, soil water drought observation and forecast is based on soil moisture calculated with hydrological models. The purpose of this work is to evaluate, if soil moisture observed with remote sensing can add information.
We used the soil water content (SWC) derived from the ERS-scatterometer. The first step of this research, presented here, is a statistical analysis of the temporal and spatial variability in SWC. A clear annual cycle was found in SWC, which is considered beneficiary in using SWC for drought observation and forecast. However the persistence in SWC seems small in summer, which is the season when drought forecasts would be most important.

Introduction
Drought monitoring and forecasting
Drought is “a sustained and regionally extensive occurrence of below average natural water availability that can have large socio-economic impact” (Tallaksen and Van Lanen, 2004). Soil water drought may cause damage to agriculture and terrestrial ecosystems. Hydrological drought may cause damage to power production, navigation and aquatic ecosystems. Droughts are projected to become more likely in the Rhine basin (KNMI, 2006) and other parts of Europe, because of climate change. Adequate drought warning systems are therefore essential in drought risk management (EU, 2007) and being developed (the European Drought Observatory).
Currently, soil water drought observation and forecast is based on soil moisture calculated with hydrological models that were originally designed for flood forecasting. The forecasts are available up to seven days ahead. This is a reasonable horizon for flood forecasting but can be considered rather short for drought forecasting, as droughts are more slowly developing phenomena.
Remotely sensed soil moisture observations may add information to the models. These observations may also be used as an important information source for longer range forecasting, because soil moisture variation is widely recognised as a slow varying phenomenon (e.g. Koster et al., 2004). However, remotely sensed soil moisture is expected to only represent the top few centimetres of the soil and the signal may therefore lack slow varying components.
Recently, WL | Delft Hydraulics (2007) performed a study into the integration of AMSR-E soil moisture with existing hydrologic models in an operational flood forecasting system. In this research, it was concluded that assimilation would not improve flood forecasts, because the remotely sensed soil moisture did not agree with a model quantity. However, another conclusion was that the remote sensed soil moisture could be beneficial as semi-quantitative information.
This work addresses the question whether remotely sensed soil moisture can be used for drought monitoring and forecast. As a first step we performed a statistical analysis into the spatial and temporal variability of the data. Some results of this analysis are presented in this paper.

ERS-scatterometer
For this work we used the soil water content (SWC) estimates from the ERS-scatterometer (Wagner, 1999). Scatterometers are radars operated in C-band that are sensitive to the water content in the topsoil. Data is available from 1992 to present at an average temporal resolution of 2-3 observations per week. The spatial resolution is 28 km.
The time-series’ length is one of the main reasons to use this data set, because the length of the series allows us to do statistical analysis. The major drawback of the dataset is that there is a gap in the data, due to instrument problems, that covers the extreme dry and hot summer of 2003. The change from a dry July to a wet August month in 2006 was however clearly visible in SWC (Fig. 1).

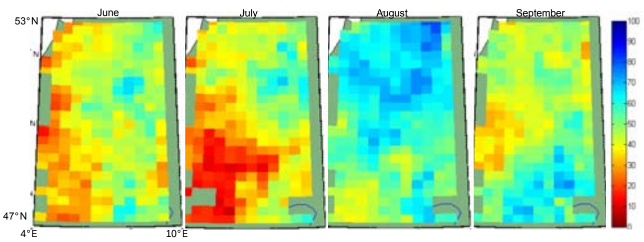

Figure 1. Soil water content (%) during the summer of 2006.

Results and discussion

The annual cycle

There is a strong seasonal signal in the Soil Water Content. The annual cycle shows similarities with the annual cycle of monthly precipitation minus potential evaporation (Fig. 2). This seasonal signal is not expected from topsoil moisture, but was also found in AMSR-E data (WL, 2007). Pixel heterogeneity and contamination of the soil moisture signal by water in vegetation or litter are possible explanations (e.g. WL, 2007, Friesen et al. 2007).

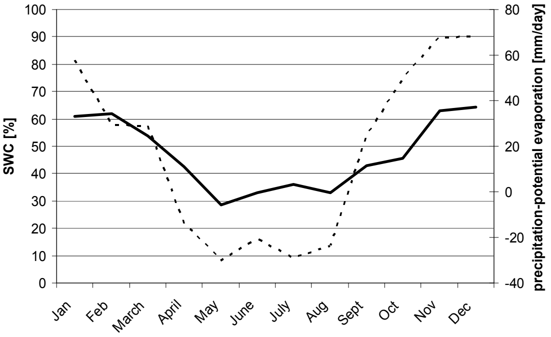

Figure 2. Spatially averaged monthly mean soil water content (SWC) over the Rhine basin (1992 to 2006). For comparison the climatologic mean precipitation-potential evaporation for the Netherlands (KNMI) is also shown (dashed line)

Lagged autocorrelations

We used lagged autocorrelations to test whether SWC can be used to forecast future SWC. Lagged autocorrelations are a measure of persistence. The lag was defined as the time between two subsequent measurements. Results for the four seasons are shown in Fig. 3. The autocorrelations are strong in winter and autumn, but weak in spring and summer. Possible explanations for this seasonal difference include a faster drying response of the topsoil due to higher potential evaporation, the connection between top-soil moisture and root-zone moisture and differences in vegetation cover.
Lagged autocorrelations for monthly average SWC were calculated for lags up to four months (not shown). Autocorrelations on this temporal scale were highest in the flat downstream areas of the basin. In agreement with this result, Vinnekov et al. (1996) found in an analysis of a large set of gravimetric samples that in flat areas the red noise (persistent) component of the soil moisture signal is large compared to the white noise component (non-persistent), whereas the opposite is the case for areas with complicated topography.

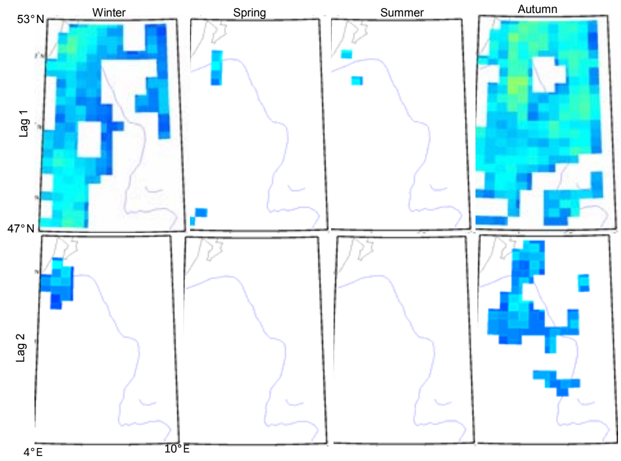

Figure 3. Significant (p=0.01) lagged autocorrelations for the four seasons.

Conclusions and outlook

Results of a statistical analysis into the spatial and temporal variability of scatterometer derived Soil Water Content (SWC) over the River Rhine Basin are presented. The presence of an annual cycle is considered beneficiary for using SWC for drought observation and forecasting. However persistence in the data seems small in summer, which is the season when drought forecasts would be of the highest value.
One of the next steps in this research is to calculate the correlations between soil moisture and Rhine discharge. Further development of drought forecast models requires integration of available data sources and models.

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Knowledge and perceptions in participatory policy processes: Lessons from the Dutch Delta

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Abstract
Water management problems are often complex and unstructured, because knowledge is uncertain and stakeholders' perceptions diverge. Dealing with these problems requires that stakeholders first reach an agreement about a valid problem-solution formulation. The initiation of an interactive or participatory process may contribute to this process of problem structuring. To get insight in problem structuring, we investigated a case study in the Dutch Delta. The case study shows that strategic *and* cognitive learning and two different types of knowledge – scientific and stakeholder knowledge – contribute to the development of an agreement about a valid formulation of a problem and its solution.

Introduction
Water problems are embedded in a complex social and natural environment. In the physical system various elements are interrelated with each other. This physical system affects various uses and users and is governed at multi-levels. Dealing with these problems is not just a knowledge problem. It is a problem of disagreement and ambiguity too. Dealing with unstructured problems requires the adoption of a process management approach. Interaction and divergence of problem perceptions are central concepts in this approach. However, too much focus on the process may also result in 'negotiated nonsense' (De Bruijn et al. 2002). Therefore, it is important to get more insight in the formulation of a problem-solution in participatory processes. This contribution focuses on two aspects of participatory processes: stakeholders' perceptions and knowledge. Literature about problem structuring, process- and network management is reflected upon experiences derived from the case study 'Fundamental discussion about freshwater supply for agriculture on Tholen & St. Philipsland'.

Theoretical framework
A problem arises if a gap exists between a normative standard and a factual situation.

Therefore, a problem is a social construct and not an objective given. Problems are unstructured if available knowledge is uncertain and disagreement exists about normative yardsticks. Because of this, it is not possible to formulate an unstructured problem apart from its solution. It is always a problem-solution combination (Van de Graaf and Hoppe 1996).

Various stakeholders have different perceptions, i.e. images of their environment and the problems and opportunities within it (Koppenjan and Klijn 2004). Perceptions determine stakeholders' objectives and are made up of their interests and perceptions of reality (Van de Riet 2003). Parts of perceptions are static and parts of perceptions are dynamic. Generally, problem formulations may change over time as a result of new information, interaction or external developments (Edelenbos 2000).

We define problem structuring as a process in which all relevant stakeholders interact with each other about the content of the problem to arrive at a joint problem-solution formulation (Hisschemöller 1993). Ideally, problem structuring results in 'negotiated knowledge', i.e. knowledge which is agreed upon and valid. To arrive at this type of knowledge, attention should be paid to the process as well as the content of a decision-making process (De Bruijn et al. 2002). Our case study is analyzed along two tracks:
stakeholders' perceptions and
the creation of a knowledge base
The development of these tracks is studied in relation to the course of the participatory process itself and external developments.

The case study
Our case study project is a fundamental discussion on freshwater supply for agriculture. This discussion concerns the islands Tholen & St. Philipsland, which are located in the southwestern Delta in the Netherlands. Agrarians in this area are supplied with freshwater from the Volkerak-Zoomlake (VZ-lake). After the construction of the Delta Works, this lake became a stagnant freshwater lake. Currently, the lake suffers from the excessive growth of blue-green algae and a poor ecological quality. To solve these problems, the Dutch government regards the re-establishment of estuarine dynamics as one

of the most important directions for solutions. However, this solution would also affect agriculture in the area. In 2006, a group of process-managers was asked to 'initiate a discussion with all relevant parties about a more natural, sustainable freshwater situation in the Delta' and 'to develop a shared insight and agreement about the most desirable direction for solutions or development'.

The participatory process

The process started with an exploration phase. Subsequently, several workshops, working sessions and an excursion were organized. Among the participants were representatives from the agricultural sector (individual agrarians, interest organizations), the nature sector (conservation organizations), and the government sector (municipality, Province, water managers). In total, about twenty people participated in the discussion. First, chances and bottlenecks were formulated, which were used to formulate possible solutions. These solutions were assessed and a choice for one solution was made. Two future scenarios about the VZ-lake have been discussed. One scenario concerns a freshwater VZ-lake and the other one an estuarine VZ-lake. At the end of the process, all participants agreed that they want to construct an alternative freshwater supply system for agriculture in order to preserve agriculture *and* to realize an estuarine VZ-lake.

Stakeholders' perceptions

From the beginning of the process, the perceptions of different stakeholders diverged. Although perceptions converged during the process, they did not become identical. Nevertheless, it was possible to reach an agreement. Two learning processes contributed to the development of an agreement. First, stakeholders learned about the problem situation which resulted in adjustment of their perceptions, *cognitive learning*. Second, interaction made stakeholders aware of their mutual interdependencies, this is referred to as *strategic learning* (Koppenjan and Klijn 2004).

Knowledge base

Prior to the participatory process, several studies were carried out by professional researchers. This resulted in an abundance of *scientific knowledge*. However, this scientific knowledge was received with great scepticism by some participants and it did not answer all questions that arose during the process. It appeared that stakeholders were able to answer many of these questions. Process managers connected this *stakeholder knowledge* with the existing scientific knowledge base. The case study confirms that stakeholders are more likely to accept information if they have been involved in the production of knowledge. Furthermore, to create context-specific knowledge various sources should be used (Eshuis and Stuiver 2005).

Conclusions

Our experiences in the Dutch Delta show that for dealing with complex, unstructured problems, learning processes related to the content (cognitive) and to the process (strategic) are relevant. Furthermore, it is important to integrate knowledge from professionals and stakeholders to create an agreed upon *and* valid knowledge base.

Acknowledgements

We would like to thank TNO, process participants and process managers for their support and cooperation.

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Perspectives in Integrated Water management

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Abstract
For developing robust and flexible water management strategies, better insight in perspectives and perspective change is required. As part of the BSIK 'Leven met water' program, in the project 'Perspectives in Integrated water management' a method for mapping dominant social perspectives, undercurrents and perspective change is developed. We identified drivers for perspective change (e.g. surprises and failure of reproduction mechanisms) and hypotheses about the direction of change. Based on a flood, we show that an event can result in different, plausible futures, depending on undercurrents, other events, the context, and the spirit of the time.

Introduction
A perspective is 'a coherent and consistent description of the perceptual screen through which people interpret the world (..), and which guides them in acting' (van Asselt, 2000, pp. 115). We approach policy according to our individual perspective how the uncertain future will look like and what we find important. However, in water research the attention paid to changes in social perspectives, and its influence on environment and policy, is very limited. In order to get more insight in social dynamics related to water issues, we assessed:

1. How can uncertainties and values be interpreted and mapped? Starting point is that a dominant perspective is most influential in society and supported by the majority of people. An undercurrent consists of people advocating an alternative point of view.
2. Why, how and in which direction can perspectives change over time? This includes brainstorming about events and developments that may weaken the dominant perspective and enforce the undercurrents.
3. Describe possible, plausible, and future perspective changes in scenarios. The dominant perspective might be reinforced ('backlash') or change towards present undercurrents.

Mapping perspectives
Different possible futures can be envisaged, depending on the perspective people may have. Different perspectives in turn will lead to the adoption of different water management strategies. According to Cultural Theory, three stereotype perspectives can be distinguished: the hierarchical (hie), egalitarian (ega) and individualist (ind) perspective (Fig. 1).

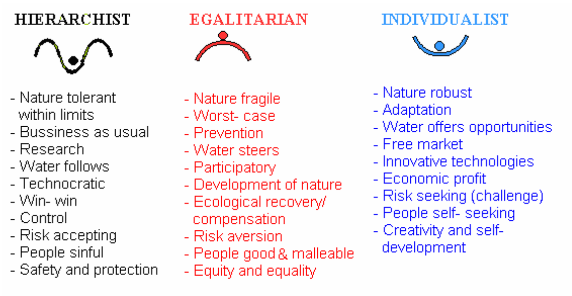

Figure 1. Overview of perspectives (van Asselt, 2000; Valkering et al., 2007) derived from Cultural Theory (Thompson et al, 1990).

A real-life perspective can be mapped by analyzing the interpretations of a specific set of beliefs along the hie, ega, or ind perspective. The set includes core beliefs (i.e. how people interpret the world and how they act upon it in general, see Fig. 1), strategic policy beliefs (water related policy principles) and operational aspects (the implementation of water policy). By scoring the number of hie, ega, or ind interpretations one obtains an aggregated index of the perspective, generally showing a mix of the stereotype perspectives considered. The aggregated index is plotted on a triangular 'perspective space' to visualize perspectives and perspective changes, see Fig. 2.

Perspective change
Perspectives can change by influence of surprises and reproduction mechanisms. Surprises are defined as developments and events which cause a mismatch between one's world view (expectations) and the observed reality (Thompson et al., 1990). Typical surprises in the water management domain would be 'a collapse of the water market' (for the individualist), 'climate change being a complete hoax' (for the egalitarian), and 'breaching of a dike' (for a hierarchist). Similarly, the failure of reproduction mechanisms (those observations that support ones perspective right) contribute to change (Valkering et al., 2007). However, perspectives are inherently robust to change. Therefore, an accumulation of surprises and failure of

reproduction mechanisms is needed to force individuals to adopt perspectives that are better suited to the reality around them (Thompson et al., 1990).

Historical perspective changes

Insight in perspective change was obtained from 4 workshops on the management of the River Meuse. The first two focused on perspectives in the past and present. Three main shifts were identified for the time span 1800 – 1995 (Fig. 2) in response to various developments (e.g. industrialization, growing environmental awareness) and events (e.g. the Sandoz incident, 93/95 floods). The present perspective was classified as hie, with individualistic and egalitarian undercurrents.

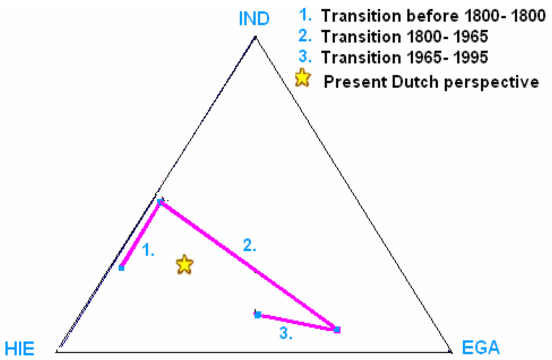

Figure 2. Visualization of historical perspective changes regarding the Meuse. The dominant perspective changed from hie, towards a combination between hie (controlling water) and ind (navigation interests and economy guides). Then the perspective moved towards ega (attention to quality of nature and water) and hie (protection against floods as guiding principle). For a detailed overview of drivers and consequences of these changes, see Valkering et al. (2007).

Future perspective change

So, how could perspectives change further towards the future? As an illustrative case we describe three possible reactions to a big flood in the nearby future. One scenario would be a reinforcement of the current hierarchical perspective (backlash). The flood is considered unacceptable. Obviously, the current 'ecological' water management approach was unsuccessful and needs to be reversed. A strong, responsible and knowledgeable government is needed to implement the necessary dike reinforcements. A second scenario could be strengthening of the egalitarian undercurrent. The flood is then interpreted as an inevitable consequence of climate change. Under influence of further dike-breaches in the flood aftermath, trust in the strategy of 'control' through dikes diminishes. People collectively decide that it is better to abandon the low-lying part of the Netherlands to make space for water for real. Decreasing population trends and a strong sense of 'community' and 'sustainability' within the EU make relocation – also outside NL - quite feasible. A third scenario would be a strengthening of the individualist undercurrent. The flood is then considered an opportunity to finally implement innovative and creative ways to tackle water related problems. Plans for floating houses and a polder in sea are developed. Continuing spatial developments make land prices rise, so that land reclamation is quite profitable. Due to a number of successful pilot projects trust in technology remains high. The concern for environmental change diminishes as environmental problems stay away.

Conclusions

Robust, flexible water management strategies anticipate on 'foreseeable' possible future changes in physical and social environments. Social uncertainties and developments can be analysed by classifying the variety of values, prioritizations and interpretations in perspectives. Perspectives can change by influence of surprises and the failing occurrence of reproduction mechanism. One event can lead to different futures, depending on for instance present undercurrents, the context, and the (non)occurrence of other events Analysis of possible transition paths of changing perspectives, allows for developing integrated, consistent story lines about how the future of water management may look like.. This, for its part, allows policy makers to be better prepared to future developments.

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Actor value orientations in Dutch water management

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Abstract
Integrated water management (IWM) has been formalized policy in the Netherlands for nearly two decades. However, management solutions are not always formulated from an integrated perspective, not taking the full range of stakeholder values into account. For IWM to gain substance, a Q-sort study was performed amongst river management actors, identifying six different value orientations on what they find important in relation to water systems and their management. The findings especially showed ethical-affective values to be important, calling for information on these values to be taken into account in the policy process.

Introduction
In the Netherlands, integrated water management is accepted as the mainstream approach for managing activities in water systems (V&W, 1998). It generally refers to a planning process in which the complete range of existing stakeholder interests (including nature) and values are taken into account. Since its introduction, however, it has been elaborated in different ways, diverging from its core meaning. In practice management solutions are not always formulated from an integrated perspective, remaining one-sided (often technical) in their scientific underpinning. For IWM to gain substance, re-orientation is necessary on what IWM should be about conceptually and scientifically.
Therefore, a study was performed to reassess the core frame of what is important and relevant within the IWM process. This was done by identifying what characteristic value orientations actors in water management hold in relation to water systems and their management, and next by evaluating the consequences of existing value orientations for the strategic elaboration of integrated water management and the input of scientific knowledge.

Method
Q methodology, including factor analysis, was used to identify latent similarities in value orientations between individuals (McKeown & Thomas, 1988). When performing a Q-sort, a participant shapes his/her viewpoints relating an issue (in this case towards water systems and their management), resulting in a classification of significant different value orientations, based on intercorrelations of individual belief patterns. The study population consisted of a broad representation of persons active in organizations that are involved in different water management sectors (government, nature conservation organizations, water-related industries etc.). A total of 56 persons participated, of which ten were women. Each participant was asked to sort and prioritize 36 statements that expressed a broad range of sentiments and positions towards water systems and were derived from scientific studies, policy documents and advisory reports. The offered set of statements was structured by a theoretical matrix that expresses nine value domains (Fig 1.).

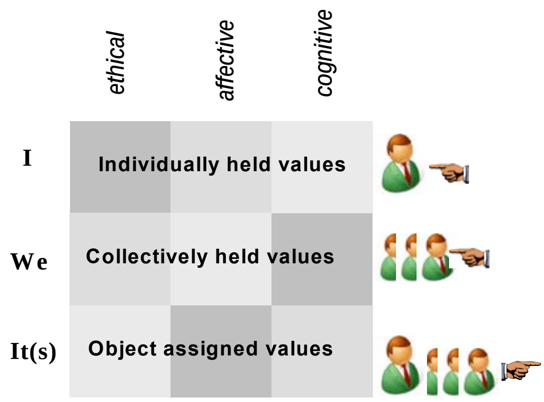

Figure 1. Value matrix

Principal components analysis with Varimax rotation was used to extract six factors (PQMethod 2.11). The factor solution accounted for 73 % of the var iance. In total, 39 Q-sorts (68%) had pure loadings on one of the six factors identified. The remaining Q-sorts loaded significantly on two factors (mixed loadings). In order to determine the meaning of each factor, a composite factor array with ranking scores was created for each factor.

Table 1. Dominant value orientations amongst actors in Dutch water management

Factor	Label	General description	Organizational background	Educational background	Dominant value types	N
1.	*Landscape rationalists*	Value water as a physical space, a landscape that is a mosaic of functions to humans	++ experts advice/research + environmental NGO's	++ engineering (land-water) + geoscience	collective-cognitive	16
2.	*Technical users*	Value the use functions of water, belief in technical control. Rejection of personal perceptions in management process	+ economic use	++ engineering (civil) + bioscience/ chemistry	cognitive-object	9
3.	*Contemplative users*	Value water-as-a-society. Balanced use in partnership with nature	+ policy + economic use	+ engineering (civil) + geoscience	ethical-collective	9
4.	*Nature participants*	Value from a personal bond with nature. Nature has Intrinsic value and needs to be conserved	+ environmental NGO's + policy	++ bioscience/ chemistry/ env. health	individual-ethical	18
5.	*Experience users*	Value personal connection to water through experiences. Water is part of society to enjoy	+ recreational & economic use + expert	++ economics/ consumer-trade	individual-affective	7
6.	*Community stewards*	Value water-as-a-community. Benefits of water should be equally shared	+ management	+ engineering (land-water) + economics	ethical-collective	12

Results

Table 1 summarizes six different value orientations that were found amongst the participants. These expressed orientations are distinctive and interpretable with the used theoretical matrix, distinguishing themselves at the individual and collective value level, as well as the objective and subjective (ethical/affective) level (Fig. 2). There are two general groupings; the first consists broadly of actors from environ-mental NGO's, governmental management and national policy actors, having ethical, broad strategic orientations with a background in bio-geoscience and land-water engineering (factors 1, 4, 6). On the other hand are economic users and local policy actors with a rational and objective reality-based orientation, having a background in mainly civil engineering and economics (factors 2, 3, 5).

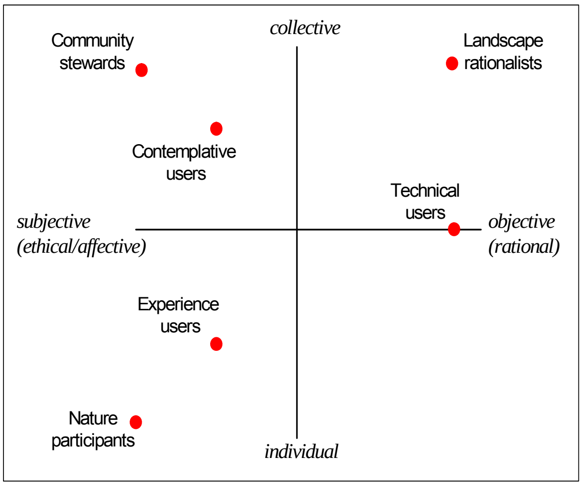

Figure 2. Orientation of factor groups

Overall, participants showed strong values towards (protecting) nature, expressing the need to adjust to the natural environment and protect it. Ethical/affective value dimensions were prominently present (Fig. 2).

Conclusions

The dominant value orientations show diversity in valuation of water systems and management. The policy process of IWM has to take this diversity into account, which calls for information on ethical-affective values especially.

Q methodology may be a policy relevant tool in IWM for consultation and environmental planning decisions through eliciting, evaluating, comparing subjective positions. Furthermore, it is a qualitative/ quantitative approach that can provide a bridge between natural- and social scientific approaches (Eden et al., 2005). Full awareness, however, is needed of its interpretative dimensions.

Acknowledgements

We would like to thank Jeroen Devilee and Theo van der Weegen for constructive discussions and statistical support.

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Historical decline of Atlantic salmon in NW-Europe

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Abstract
Analysis of zoo-archaeological and historical data of Atlantic salmon stock development shows a remarkable decline from the Middle Ages onwards. Apparently, the species encountered great difficulties in successfully reproducing from that time on. The most probable cause for this decline are thousands of watermills built in the tributaries of Europe's large rivers from the Early Middle Ages on. These watermills both blocked upstream migration and made spawning sites unsuitable for successful reproduction. In order to restore viable Salmon populations in Europe's large rivers, far more attention has to be paid to rehabilitation of lower order streams.

Introduction
The Atlantic salmon (*Salmo salar*) has become the symbol of ecological degradation of river systems in NW-Europe, especially for the rivers Rhine and Meuse. Traditionally, the main reasons for degradation are believed to be intensive fisheries, pollution and especially river regulation, particularly in the 19th and 20th century. According to Hoffmann (1996), however, it is unjust common thought that the Rhine and its major tributaries had only suffered little before 19th and 20th century canalizing and embanking. Our hypothesis is that this is also the case for Atlantic salmon and that watermills in lower order streams are historically important stressors by blocking upstream migration and altering favorable reproduction conditions.

Method
We studied developments in Atlantic salmon stocks by means of Dutch zoo-archaeological data (Bone-info; www.archis.nl) and historical publications containing time series on fishery taxes and market prices. In the zoo-archaeological approach we compared the number of sites in the Netherlands with salmon remains with the number of sites containing Pike (Esox lucius) remains in five periods. Due to the fact that salmon bones contain higher levels of fat that turn into fatty acids after decay and subsequently dissolve the rest of the bones, their remains decay quicker than that of Pike. If actual stocks of both species would remain stable over time, one would therefore expect an increase in the ratio between the number of sites with remains of Atlantic salmon and those with Pike remains. Historical time series were based on: Halard (1982): 1260-1410, Van der Woude (1988): 1650-1800, Martens (1992): 1798-1827 and De Nie (1997): 1885-1939. These time series were indexed in order to be able to compare and link series of different origin. In case data was lacking over specific periods of time, developments were extrapolated by fitting a trend line (Eqn. 1; with c being a constant).

$$\frac{1}{\sqrt{c * time}} \qquad (1)$$

Data from developments in watermill construction in the Rhine and Meuse catchment areas were obtained from *www.molendatabase.com*. Furthermore, we derived data from Domesday Book (Williams and Martin, 2004), a survey of rural estates in 11th century England and compared these data with present-day distribution of Salmon in the UK.

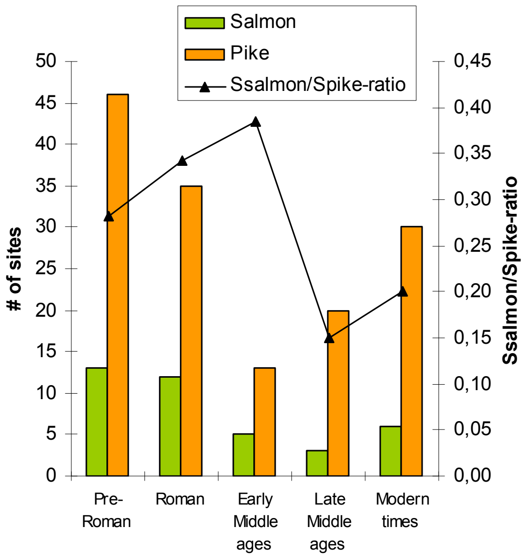

Figure 1: Number of sites with zoo-archaeological records of Salmon (Ssalmon) and Pike (Spike) in the Netherlands and the ratio between them over five periods of ca 500 years each.

Results and discussion
Analysis of the zoo-archaeological data (Fig. 1) shows that during the transition from the Early to the Late Middle Ages a decrease in the Salmon-Pike ratio occurs, indicating a major decrease in Atlantic salmons stocks during this period.
From Fig. 2 it becomes also apparent that salmon decline in NW-Europe started well before the great river regulation works in the 19th and 20th century. By the beginning of the

18th century Atlantic salmon stocks were already decimated. At the same time watermills (in this case in the lower order streams of the Rhine and Meuse catchment areas) were on the increase, thus blocking large parts of the upstream spawning areas of salmon and altering favorable conditions for spawning and nursery.

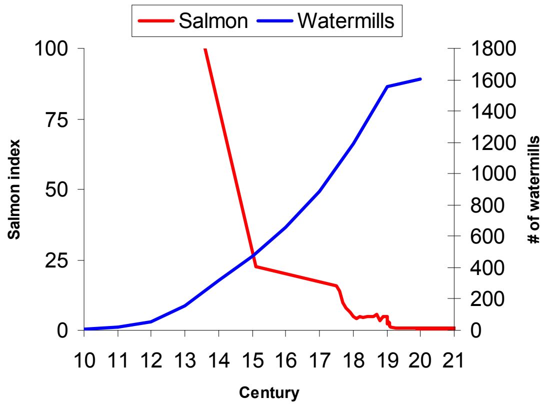

Figure 2: Decline of Atlantic salmon in NW-Europe (indexed; 1360=100%; left y-axis) and increase of watermills in the catchment areas of Rhine and Meuse (right y-axis).

In Domesday Book (Williams and Martin, 2004) over 6000 watermills are reported to be existing in 11th century England. These watermills were not evenly distributed over England. Especially in the north- and southwest watermills were far more scarce. In the present day distribution of Salmon in the UK (Fig. 3), this historical distribution of watermills is still visible: Salmon and watermills seem to exclude one another. This appears to be the case already in medieval times since the five locations for which Salmon is mentioned in Domesday Book are all situated in the peripheral regions where watermills were scarce or absent.

Conclusions

Our research confirms Hoffmann's statement that river systems in NW-Europe were already severely ecologically affected in the Middle Ages. The construction of watermills in lower order streams appears to have had a major impact on Atlantic salmon stocks (and probably also on other aquatic organisms). In order to restore salmon stocks and the complete river ecosystem in general, much more attentions has to be paid to lower order streams, a task – given the immense magnitude of historical alterations – that will not prove to be easy.

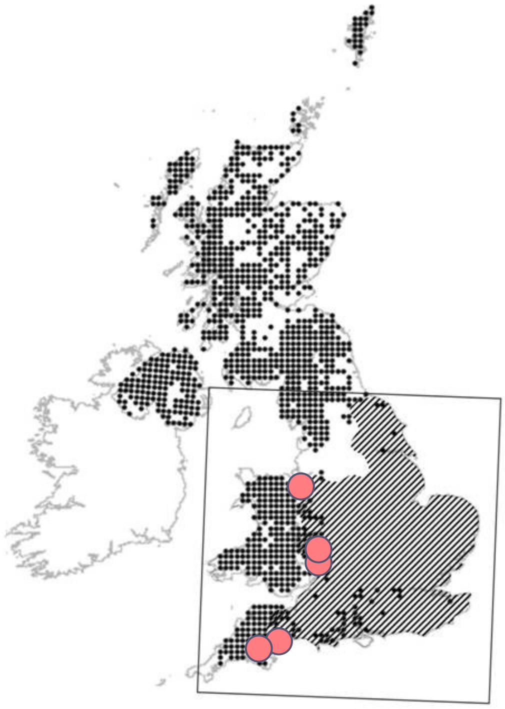

Figure 3: Present day distribution of Atlantic salmon in the UK (black dots) and main area of watermill distribution in the 11th century (shaded area). The box indicates the area referred to in Domesday Book (with the exception of the larger part of Wales). The pink dots refer to reports of Salmon in Domesday Book.

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River bed management in the Nieuwe Merwede

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Abstract

Integrated solutions to the problems posed by the inheritance of contaminated sediments in the Dutch lowland-rivers are available, yet expensive. In this study, measures are tested for the Nieuwe Merwede. Due to a trend of clean sedimentation which will cover the contaminated layer, dredging the top layer (50 cm) of contaminated areas will minimize the possibility that erosion of contaminated sediments can occur in future. Even when combined with maintenance dredging of the shipping channel, currently contaminated layers will stay in place. This is not the case if the shipping channel is deepened further than the maintenance depth. Climate change does does not affect these conclusions.

Introduction

For years the large volumes of severely contaminated sediment deposits in the lowland-rivers have been a practically insolvable problem for Dutch water managers. Now that the quality of sediment from upstream has improved to acceptable chemical levels, a solution to this problem can be implemented. Treatment of contaminated sediment is still extremely expensive, as is deposition elsewhere. This makes storage of deeper layers of sediment in their original location preferable, as long as they do not pose any human or environmental threat. This study researches possibilities to integrate a solution to this problem with other river-functions such as shipping and safety. The study area is the Nieuwe Merwede, a branch of the Rhine river (Fig. 1).

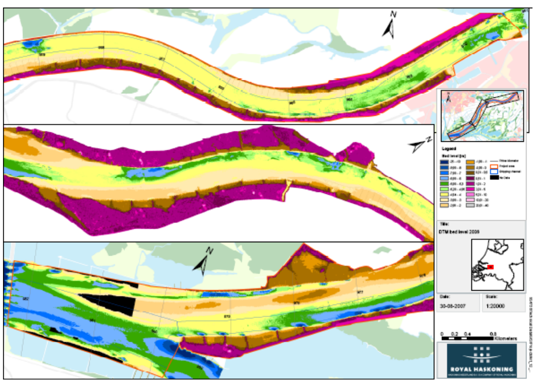

Figure 1: Two-dimensional map of bed levels in Nieuwe Merwede. The shallow sandbanks (brown) are heavily contaminated. Green and blue areas comply with the demanded shipping-depth

Goal & method study

The findings of this study consist of robust alternative measures for sediment-remediation (clean-up) and management of the river bed until 2037, with the influence of climate change taken into account. The applied method is shown in Fig. 2.

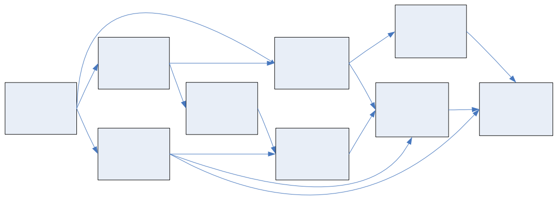

Figure 2: Research method

Objectives alternatives

Long-term policy defined in national and European laws provide a basis on which the objectives for river bed management alternatives are designed for 30 years:
Guaranteed depth for shipping is 4,95 m; no maintenance dredging during 30 years
No severely contaminated sediments in:
 morphologically active top layer of 50 cm
locations that show large-scale erosion in long term simulations
No rise of normative water levels due to these measures

SOBEK-RE model

An existing one-dimensional morphological model of the Rhine-Meuse delta is applied (Mol, 2004). Lack of detailed maintenance-dredging data complicates validation.

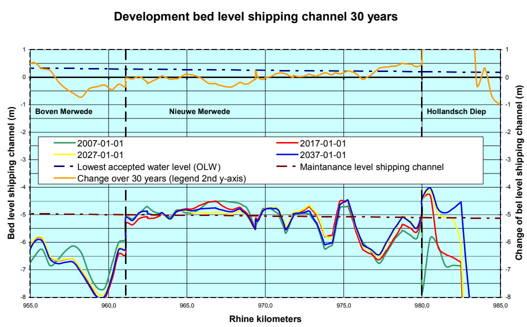

Figure 3: Morphological development Nieuwe Merwede in 30 years

The model is accepted on basis of long term simulations (Figure 3), showing that, a morphological equilibrium has almost been achieved (match to reality).

Sensitivity climate change

The average bed level is hardly sensitive to extreme climate change (KNMI, 2006). Levels decline due to more frequent and intense extreme discharge events (+/- 20 cm) and rise due to sea-level rise (+/- 15 cm). These effects almost even each other out, as shown in Figure 4. The difference is smaller than the model-uncertainty (Van Deursen, 2002 & De Wit et al., 2007).

Results

Each of five (A,..,E) alternative strategies is implemented in SOBEK-RE (as in purple line Fig. 5) and tested on 4 criteria: shipping, environment/ecology, security and cost. Alternatives A and C concentrate on fulfilling shipping demands, whereas Alternative B aims at maximising the environment/ecology score. Alternatives D and E consist of integrated measures in which all goals are combined. An example of measures is shown for the most successful Alternative strategy D in Fig. 5. The summary of results for all alternative measures is shown in Table 1.

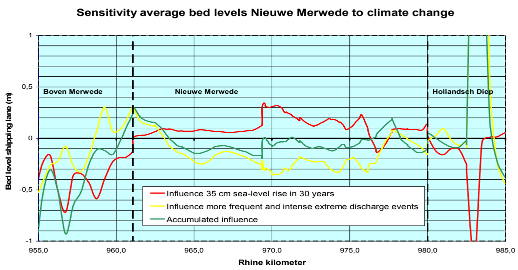

Figure 4: Sensitivity of bed levels to climate change

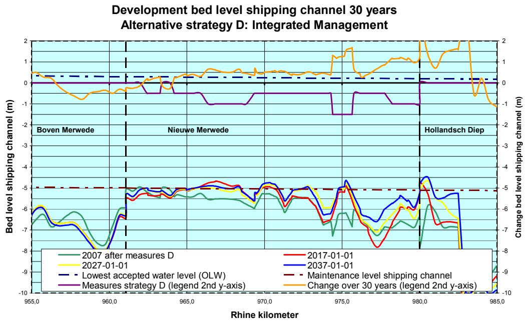

Figure 5: Measures and morphological development for alternative strategy D: "Integrated Management"

Table 1: summary results all alternative strategies

Alternative strategy	Ship-ping ++ = best -- = worst	Environ-ment/ ecology ++ = best -- = worst	Secu-rity 1 = best 6 = worst	Cost Index = 100 (Average cost)
Do nothing	--	0	6	0
A: Shipping	0	--	4	41
B: Complete remediation	--	++	2	132
C: Shipping with sediment trap	+	--	5	34
D: Integrated management	+	0	1	137
E: Integrated management with cover	--	+	3	156

Conclusions

- Successful integrated management is technically viable, yet expensive
- Dredging once in 30 years is impossible; maintenance dredging is indispensable
- A most effective management strategy will contain:
  - o Nautical dredging no lower than maintenance level
  - o Monitoring of bed level shipping channel, combined with maintenance dredging when necessary*
  - o Dredging top layer (50 cm) of contaminated sediments, combined with natural or artificial cover

*Confirmation needed through further research

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River groynes for the future

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Abstract
The Island Groyne contains significant improvements in terms of quality of the fairway (mainly through minimising depth limitations and improving the flow conveyance), ecological connectivity and potential (in line with the EU Habitats Directive and Water Framework Directive), quality of landscape and the perception of groynes in it, sustainability, and morphological stability of the river. It is also possible to effectively reverse on-going bed degradation. The morphological improvements result in a significant reduction in the amount of maintenance dredging required, as well as structural maintenance (outflanking), which makes innovative groynes economically attractive.

Background
In the Netherlands, since 1830, river groynes have been needed to fix the fairway in the river bed and to improve the (safe) discharge of ice. These conventional groynes have proven to be reasonably effective up until today. However, the current context of the river groyne has changed significantly and their performance must now be considered in a modern and far more complex context. This contemporary context comprises contradictory demands, such as reduction of peak water levels and improvement of the fairway in terms of navigability. Additionally, it is considered necessary to restore and improve ecological values, spatial quality and to reverse the ongoing bed degradation of the river caused primarily through river normalisation and training.
These modern demands have given rise to reconsideration of the current river groynes and harmonisation of river hydraulics and morphology. As the responsible authority for navigation and flood safety on the main rivers in the Netherlands, Rijkswaterstaat, in association with CUR, organised the design competition “Groynes for the Future”: the 21th century demands were to be united in an innovative groyne design (CUR, 2006). This paper briefly reviews a prize-winning design of this competition: the Island Groyne. For a detailed description of an environmental assessment and a cost-benefit analysis reference is made to Van Heereveld et al. (2006).

Figure 1. Artist impression of the Island Groyne.

The Island Groyne
The Island Groyne (Fig. 1) consists of an opening made in the existing groyne and a lengthened groyne head in the direction of flow (the Island). The opening is about 60 m^2 and is constructed near the groyne head where flow intensity is greatest. The opening is submerged for about 300 days per year and allows for a reduction in peak water level of about 7 cm. A larger opening would be more difficult to compensate in terms of negative effects on the fairway quality and compromise the optimum balance between reduction of peak water levels, fairway improvement, ecology, quality of landscape and reversing the on-going bed degradation. This practical limitation also implies that a significant part of the existing groynes can remain intact which is not only favourable for ecology and quality of landscape but also for sustainability and cost. Moreover, since the opening is made near the groyne head, current attack is diverted from the river bank improving bank stability, fairway morphology and the need for maintenance on the groynes themselves (mainly outflanking and removal of vegetation).
In case of the conventional groynes, sediment is deposited in the groyne fields during periods that groynes are submerged, while ship-induced water motion is the primary driver for sediments eroding from the groyne fields during low water season (emerged state). The opening in the Island Groyne results in a more gradual flow distribution from the main channel to the river bank. The resulting sheltering effect will decrease the amount of sediment

exchange between groyne field and fairway so that more sediment can be held in the groyne fields. Hence, sediment load on the fairway is limited during low water season as well as the local shortage of water depth due to temporal bed changes in the fairway.
The Island further enhances the sheltering effect of the opening on the conditions in the groyne fields and also lowers (ship-)wave intensity. The visibility and navigability improves because the river is better defined when seen from the bridge of a vessel. Also, the Island can be fitted with two rather than one radar beacon as a further improvement of the fairway.
The primary reason for lengthening the groyne head is to limit the amount of constriction scour and the downstream deposit of eroded material, which is important for depth limitation in the fairway. Altogether, the current amount of maintenance dredging required to keep the fairway navigable (usually during emerged state) is significant, but will be minimised through the Island, and effectively compensate the increasing flow area on the quality of the fairway. Over-compensation is also possible so that bed degradation may be stopped.

Exciting ecological improvements

The opening in the groyne and the shelter created in the groyne fields offers opportunities for improving ecological development. An increase in number and diversity of species is expected. Migration of species is also improved as the lower flow velocities in the opening are easily negotiated as opposed to the higher flow velocities around the groyne head and in the main channel in the existing situation. The sheltering also offers a more gradual transition from main channel to land, which is important for the quality of landscape and the way the landscape is perceived. By keeping the existing groynes intact and using familiar materials to construct the new parts, the cultural heritage that the groynes represent in the Dutch river landscape is justified. Yet, the Island Groyne bears a clear 21st century signature.

Meeting cost-effective high standards

In terms of cost, the Island Groyne is competitive because use is made of the existing river training structures, doing justice to the capital it represents. Taking into account the lower cost of maintenance of the fairway and the groyne itself, the Island Groyne is even more competitive and sustainable than other types of groynes which do not comprise the optimum benefits of the Island Groyne.

Conclusions

With the Island Groyne, it is possible to establish peak water level reduction without consequences for the quality of the fairway. Moreover, improvement is possible, including the reversal of the on-going bed degradation. The design of the Island Groyne is robust and flexible: its performance under current and future conditions is easy to maintain, adding to the designs sustainability.

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The influence of global warming and thermal pollution on the occurrence of native and exotic fish species in the river Rhine

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Abstract
The fish fauna of the Rhine river branches in the Netherlands shows remarkable changes from the 20th century onward. Over the period 1940-1979, the species richness of rheophilous species has declined due to habitat deterioration. In spite of recent improvements of water quality and habitat rehabilitation, native fish fauna has only partly recovered. The number of exotic species (i.e. non-native immigrants and deliberately and accidentally introduced species) has strongly increased. Exotic species tolerate higher maximum temperatures than native ones. Based on species sensitivity distributions it is predicted that a future increase in water temperature will affect a higher percentage of native fish species than of exotic ones.

Introduction
Several large rivers in Western Europe show rising water temperatures, due to thermal pollution and global warming. This paper presents preliminary results of a study on the influence of water temperature on fish fauna. We hypothesize that rising river water temperature is a limiting factor for (recovery of) native fish fauna. We answer the following research questions:

1. What are the temporal trends of the minimum, average and maximum water temperature of the river Rhine?
2. Which fish species have been recorded in the Rhine river branches in the Netherlands?
3. What are the species sensitivity distributions for temperature tolerance of these species?

Material and methods
Data on water temperature from the river Rhine at Lobith were obtained from RIZA (2007). An existing database on the distribution of fish species in the freshwater section of the river Rhine in the Netherlands (Van den Brink et al., 1990) was updated, using data of recent fish surveys (Raat, 2001; Leuven et al., 2008). In total 60 fish species were recorded from the 20th century onward (38 and 22 native and exotic species, respectively). This database was completed with data on temperature tolerances of fish species. Minimum and maximum temperature tolerances were obtained from FishBase Consortium (2007) and updated when recent scientific literature referred to lower or higher tolerance values, respectively. For 35 native fish species (92%) and 22 exotic ones (100%) data were available to construct species sensitivity distributions for minimum and maximum temperature tolerance. Lognormal distributions were used to relate the potentially affected fraction (PAF) of native and exotic species to temperature.

Results
The presence of fish species remarkably changed over the last century (Fig. 1). The number of native rheophilous species declined over the period 1900-1979. The native fish fauna partly recovered in recent decades, while the number of exotic species strongly increased (in particular after the opening of the Rhine-Main-Donau canal in 1992).

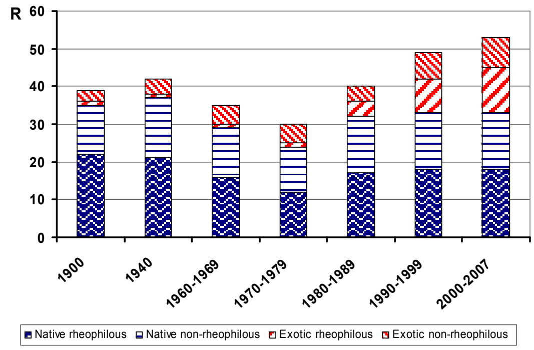

Figure 1. Species richness (R) of fish fauna in the Rhine river branches in the Netherlands.

The minimum, average and maximum water temperature of the river Rhine increased over the period 1908-2005 (Fig. 2).

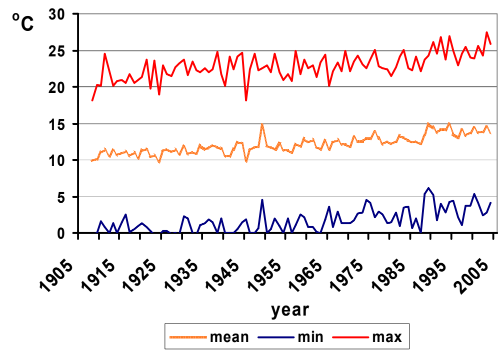

Figure 2. Water temperature of the river Rhine at Lobith.

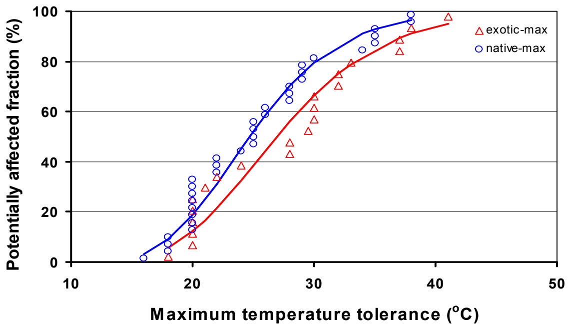

Figure 3. Sensitivity distribution for maximum temperature tolerances of native and exotic fish species in the river Rhine. Curves represent a lognormal distribution with average and standard deviation based on data points.

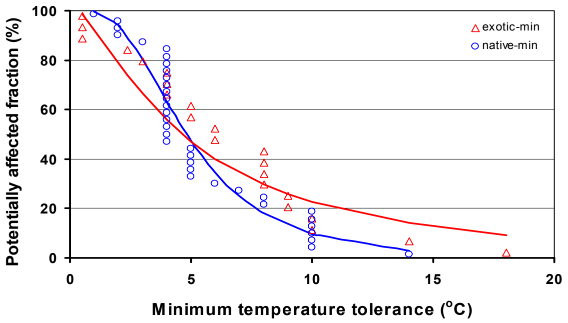

Figure 4. Sensitivity distribution for minimum temperature tolerances of native and exotic fish species in the river Rhine. Curves represent a lognormal distribution with average and standard deviation based on data points.

The lognormal species sensitivity distributions remarkably differed for native and exotic species (Fig. 3 and 4). Native species show lower maximum temperature tolerances than exotic ones. However, the slopes of the lines for maximum temperature tolerance are similar (0.10 and 0.11, respectively). Maximum temperature tolerance values potentially affecting 50% of the native and exotic species are 24.7 and 26.9 ^{o}C, respectively. Minimum temperature tolerance values potentially affecting 50% of the native and exotic species are 4.8 and 4.6 ^{o}C, respectively. The slopes of the lines for minimum temperature tolerance of the native and exotic species differ (0.24 and 0.44, respectively).

Discussion

In spite of recent improvements of water quality and habitat rehabilitation, native fish species did not completely recover (Fig. 1), which may be partly clarified by increase of temperature stress (Fig. 2). The number of exotic species continuously increased over the last century, in particular after the opening of the Rhine-Main-Donau canal in 1992. Exotic species tolerate higher maximum temperatures. Increasing water temperature of the river Rhine has been attributed for 2/3 part to thermal pollution and for 1/3 part to climate change (Ligtvoet et al., 2006). Notwithstanding a stand still or reduction of thermal pollution, for the 21th century a further increase in water temperature is predicted due to climate change (+1 to 4 ^{o}C). Species sensitivity distributions for temperature tolerance of fish species indicate that native species (in particular rheophilous species; not shown) will be more affected than exotic ones.

Conclusions

- In total 60 fish species were recorded from the 20th century onward (38 and 22 native and exotic species, respectively).
- The species richness of native (rheophilous) species in the Rhine river branches gradually declined over the period 1900-1979 and partly recovered in recent decades. The number of exotic species strongly increased.
- Over the last century, minimum, average and maximum water temperature of the river Rhine increased with circa 0.5 ^{o}C per decade, due to thermal pollution and climate change.
- Exotic species tolerate higher maximum temperatures than native ones.
- Further increase in water temperature due to climate change will deteriorate a higher percentage of native fish species than exotic ones.

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Impact of river management strategies on the biogeomorphological functioning of the lower Rhine floodplains

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Introduction

The lower Rhine floodplains play an important role as sinks of suspended sediments and pollutants and have a key role in ecological transformation processes along the river continuum. Major shifts in river functionality and landscape have occurred in the past. In the future, sea level rise (Van den Hurk et al., 2006) and expected higher peak discharges from the catchment (Middelkoop et al., 2001) necessitate landscaping measures to maintain safety standards for the embanked area, while river functions such as shipping, nature, housing, and recreation, demand other measures, and preserving the status quo is favoured for agriculture and the river as a carrier of cultural-historic values require. Figure 1 shows the well-known landscaping options that are available within the river, but the type and location of these measures is hotly debated (Braakhekke, 2007). How we shape the fluvial environment of a regulated river such, as the river Rhine, largely depends on what we value. The value system in itself is, however, rarely taken into account specifically in the planning process. Middelkoop et al. (2004) consider different perspectives on river management, but do not take the hierarchic nature of the development into account. In addition, the biogeomorphological effects, such as the deposition of sediment and pollutants or the exposure of the food web to heavy metals, are often overlooked. Therefore, we set two aims:

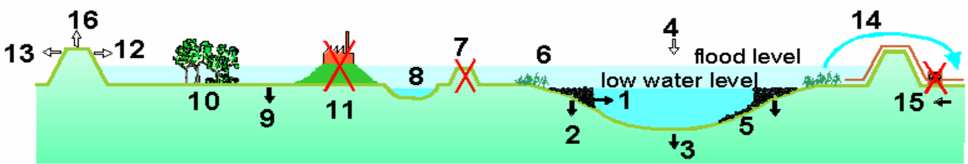
1. Establish three scenarios for the development of future fluvial landscapes based on the value system as described in Spiral Dynamics (SD; Beck and Cowan, 1996).
2. Evaluate the scenarios with respect to the ecological functioning of the river reach. We focus on flooding, deposition of sediment and pollutants, and the ecological implications, such as habitat patterns and the poisoning of the food web.

Scenario development based on Spiral Dynamics

We apply Spiral Dynamics to river management. SD models the evolution of the biopsychosocial system along a continuum that forms a spiral. Each of the eight levels along the spiral is colour-coded and represents specific stage of development. Each of the higher levels is more complex and inclusive. The spiral provides a map of different value systems, whereas the dynamics describe transitions up or down along the spiral. For a full description of SD the reader is referred to Beck and Cowan (1996) and Graves (2006).

In accordance with this model, we present three prospective scenarios for the layout of the fluvial landscape in 2060. Table 2 gives key aspects for each scenario of river management and implementation. The design discharge for each scenario is set to 17,000 m^3/s. The scenarios are:

1. Green: strengthening of the green value system (consensual and ecologic).
2. Orange: reverting to the orange value system (rational and materialistic).
3. Yellow: shifting to the yellow value system (integrative and flexible).



1 = narrowing of the main channel, 2 = lowering of the groynes, 3 = dredging, 4 = redumping of sediment, 5 = permanent layer, 6 = natural bank, 7 = removing minor embankment, 8 = digging a secondary channel, 9 = floodplain lowering, 10 = nature development, 11 = removing of raised areas, 12 = dike reinforcement, 13 = dike repositioning, 14 = retention, 15 = obstructing lateral inflow, 16 = dike raising

Figure 1 Possible landscaping measures, the choice depends largely on our value system

Table 2. Overview of the scenarios based on green, orange and yellow river management.

Value system	River management	Implementation
GREEN • Living with the human element • Getting along with others • Consensual • Feelings, sensitivity and caring supersede cold rationality	• Polder mentality, local communities have a say • Focus on ecology • Dike raising is no option • Multidisciplinary • Natural arrangement	• Space for the river combined with ecological restoration • Solutions for individual floodplain sections • Groyne lowering
ORANGE • Conquering the physical universe as to overcome want • Oriented at technology and competition • Pragmatic • Play the game to win • Manipulative towards the earth's resources	• Centralized authority • Cost-benefit analyses • Dike raising is a cheap option • Technocratic • Large infrastructures • Blueprint	• Nature is a source of welfare • Dike raising • Groyne lowering • Removal of hydraulic bottlenecks • Removal of flow obstructing vegetation • Removal of minor embankments
YELLOW • Restoring viability in a disordered world • Integrative • Existential magnificence supersedes material possessions • Differences can be integrated into interdependent natural flows	• Spatially coherent plan for the whole river section • Interactive • Local communities participate from the design phase • Water as the guiding principle • Dike raising is an option when needed	• Side channels follow the historic swale channels • Floodplain lowering • Local initiatives in line with the overall direction • Adaptive in incorporating novel techniques

Input generation and modelling

Each of the scenarios was translated into specific landscaping measures for the River Waal between Lobith and Gorinchem. Measures were chosen using two workshops attended by river management specialists. At present, the measures have been translated to topographic changes. The next steps include:

Establishing ecotope transition matrices for changes in land management.

Running the hydrodynamic model WAQUA for a series of discharges.

Computing the year-average deposition of sediment and heavy metals using the SEDIFLUX model.

Compute the exposure of the food web to heavy metals.

Determine the ecological value using the BIOSAFE model.

Conclusions

We have established three scenarios for future landscaping measures that specifically take into account the value system of the river management. These scenarios, green (consensual), orange (technocratic) and yellow (integrative), have been translated into model input that will serve the assessment of the biogeomorphological implications.

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